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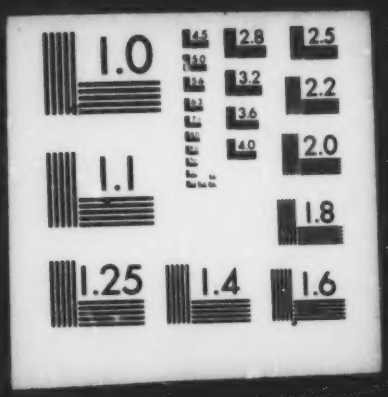

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COMPREHENSIVE ANALYSIS OF TIME-CONCENTRATION RELATIONSHIPS AND VALIDATION OF A SINGLE-SOURCE DISPERSION MODEL

Michael T. Mills, et al

GCA Corporation

Prepared for:

Environmental Protection Agency

March 1975

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This report presents an analysis of SO_2 time concentration relationships in the vicinity of a power plant and a validation of the EPA Single Source model using concentration and meteorological data collected in the same area. The concentration relationships studied were peak 1-hour to average 3-hour and peak 1 hour to average 24-hour concentration ratio distributions and the effect upon the statistics of these distributions of variables such as wind speed, atmospheric stability, hour of the day, and peak 1-hour concentration itself. The principal finding of the validation exercise was that the model underpredicted SO_2 concentrations for all 4 receptor locations in the study area. The agreement between measured and calculated concentrations was not noticeably improved by the use of more accurate and detailed emissions and meteorological data bases. Although the model predictions were improved somewhat by the inclusion of plume rise retardation effects due to the plant structure, the model appears to underestimate the degree of lateral plume spread.

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COMPREHENSIVE ANALYSIS OF TIME-CONCENTRATION RELATIONSHIPS AND VALIDATION OF A SINGLE-SOURCE DISPERSION MODEL

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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COMPREHENSIVE ANALYSIS OF TIME-CONCENTRATION RELATIONSHIPS AND VALIDATION OF A SINGLE-SOURCE DISPERSION MODEL

by

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GCA/Technology Division
Bedford, Massachusetts 01730

Contract No. 68-02-1376, Task Order 5
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EPA Project Officer: Russell F. Lee

Prepared for

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Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

March 1975

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ERRATA

COMPREHENSIVE ANALYSIS OF TIME-CONCENTRATION RELATIONSHIPS AND THE VALIDATION OF A SINGLE-SOURCE DISPERSION MODEL

Final Report

Contract No. 68-02-1376
Task Order No. 5

Page 59 - Table 11, column entitled, "95% 1-3 hour"; entry for Paradise should read ≈1 rather than 0.99.

Page 60 - Sentence (b) under Standard Error of Estimate should read:

(b) Canal Validation - The standard error for the four stations ranged from 3.2 to 4.0 times the mean measured value.

Page 61 - The last sentence under 3(b) should read:

The correlation between the logarithms of concentrations were not calculated due to the large number of zero concentrations predicted by the model.

Page 61 - Delete the second sentence in the last paragraph.

Page 69 - The figure caption should read:

Figure 22(d). Cumulative frequency distribution for 1 hour SO_2 concentrations at station 4 (plume rise retardation included)

GCA CORPORATION
GCA/TECHNOLOGY DIVISION
Bedford, Massachusetts

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This report presents an analysis of SO_2 time concentration relationships in the vicinity of a power plant and a validation of the EPA Single Source model using concentration and meteorological data collected in the same area. The concentration relationships studied were peak 1-hour to average 3-hour and peak 1 hour to average 24 hour concentration ratio distributions and the effect upon the statistics of these distributions of variables such as wind speed, atmospheric stability, hour of the day, and peak 1 hour concentration itself. The principal finding of the validation exercise was that the model under predicted SO_2 concentrations for all 4 receptor locations in the study area. The agreement between measured and calculated concentrations was not noticeably improved by the use of more accurate and detailed emissions and meteorological data bases. Although the model predictions were improved somewhat by the inclusion of plume rise retardation effects due to the plant structure, the model appears to underestimate the degree of lateral plume spread.

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Project direction and guidance were given by Mr. Russell Lee of the Source-Receptor Analysis Branch, Monitoring and Data Analysis Division, EPA, Durham, North Carolina, who served as Project Officer, and by Mr. Herschel Slater, Chief of the Source-Receptor Analysis Branch.

SECTION I

INTRODUCTION

BACKGROUND

Reliable tools for the estimation of SO_2 concentrations downwind from large power plants are urgently needed to guide environmental and energy related policy decisions. Most mathematical dispersion models for the prediction of SO_2 concentrations provide estimates over unit time periods which are either very short (up to 1 hour) or very long (seasonal or annual). For example, the plume parameters given by Turner[1] and developed principally from earlier work of Pasquill, Cramer, and Gifford are based on experimental data much of which was collected over 10- and 30-minute periods. Power law relationships by which concentrations from point sources are linked to time are generally considered to be valid only over averaging times which range from a few minutes to perhaps 1 or 2 hours. National ambient standards for SO_2, however, include standards for 3-hour and 24-hour time periods. The method currently favored for estimating 3-hour and 24-hour concentrations is to average concentrations that have been predicted for the component 1-hour periods. A second method, based on the development of peak-to-mean ratio statistics, has been suggested by Montgomery, Carpenter, and Lindley.[2] To date, very few sets of field data have been used to test the adequacy of either estimation technique.

PURPOSE OF STUDY

The purpose of this study was twofold:

1. to analyze time-concentration relationships of measured air quality data in the vicinity of a large elevated point source, paying special attention to the ratios of 1-hour to 3-hour and 1-hour to 24-hour concentrations, and

2. to conduct validation studies of an EPA concentration model designed to estimate concentrations due to a single source for averaging times of 1 hour, 24 hours and 1 year, with emphasis on the 24-hour value.

The analytical procedures to be followed in this study were, to a large extent, to parallel those used by Klug[3] and Montgomery et al[2] in their analysis of TVA data so that comparisons could more easily be made between the results obtained at two sites having substantially different plant capacities and effective stack heights.

SUITABILITY OF CANAL PLANT DATA

Plant Description

The Canal Plant is located on the south side of the Cape Cod Canal about 1.6 kilometers from the east entrance on Cape Cod Bay. The data used in this study were collected during the 3-year period from 1971 to 1973. During this period, the plant consisted of a single oil-fired unit with a generating capacity of 560 megawatts. The top of the stack was approximately 91 meters above grade and 5.59 meters in diameter. The main power plant structure to the north of the stack totally enclosed the turbine generator and the boiler. The roofs of the turbine and boiler rooms were, respectively, about 30 and 59 meters above grade.

In 1974, the 91-meter stack serving Unit 1 was replaced by a 152-meter stack in preparation for the start up of a second 560 megawatt

unit sometime in 1975. It is expected that continued air quality monitoring during these second and third phases of plant operating history will provide additional valuable data for validation studies.

Site Characteristics

Figure 1 shows the geographical location of the Canal Plant, near the northwestern boundary of Cape Cod. The north shore of the Cape extends eastward from the plant a distance of approximately 50 kilometers before turning sharply to the north. Cape Cod is widest at its western end where it extends from the canal southward toward Falmouth and Woods Hole, a distance of some 25 kilometers. The topography of the central portion of Cape Cod and the adjacent areas of Massachusetts bordering Buzzards Bay and Cape Cod Bay comprises gently rolling terrain with elevations generally below 60 meters. Maximum elevations in the region of interest occur in the western end of the Cape and reach approximately 90 meters. Much of the area is covered with scrub pine forests and low vegetation.

Overview of Monitoring Program

The New England Gas and Electric System has operated an air quality monitoring network in the vicinity of the Canal Plant ever since the plant was first put in operation in 1970. As part of the network, SO_2 concentrations are measured at four or more locations on a continuous basis with Ultragas SO_2 Analyzers manufactured in Germany by H. Wosthoff. These instruments measure sulfur dioxide by the increase in conductivity of an acidified hydrogen perioxide solution and have a full scale reading of 0.4 ppm. The instruments do not conform to the reference method for sulfur dioxide or to any of the specified equivalent methods.[4] The have, however, been extensively studied and one comparison showed a correlation coefficient of 0.99 with the West-Gaeke method.[5]

Figure 1. Map of eastern Massachusetts and Rhode Island showing locations of the Canal Plant. Meteorological observations were used from Quonset Point Naval Air Station and Nantucket Island

Throughout the program the instruments have been attended on a day-to-day basis by a chemist from the utility. Major maintenance and routine calibrations are performed in the GCA/Technology Division laboratories. The SO_2 monitors are calibrated dynamically using a carefully controlled and calibrated permeation tube - dilution system capable of creating sulfur dioxide concentrations over most of the instruments' measurement range.

This instrument operates on the conductimetric principle and provides a continuous real-time chart trace and a tape printout giving date, time, and average concentration over consecutive 30 minutes. The monitoring program is being carried out under the direction and with the engineering support of the GCA/Technology Division. The New England Gas and Electric System provides field engineering services and takes care of the day-to-day operation of the network. GCA provides field support as required, instrument calibration and data analysis and interpretation. The locations of the SO_2 monitors with respect to the Canal Plant are given in Figure 2 and Table 1. Station No. 4 was moved as shown in Figure 2 on 30 October 1973.

Table 1. LOCATION OF SO_2 MONITORING STATIONS

Station number	Bearing from plant (deg)	Distance from plant (km)	Elevation of terrain (m)
1	119	4.72	10
2	138	2.32	4
3	224	1.43	40
4 (Before 10-30-73)	312	1.96	20
(After 10-30-73)	320	4.83	40

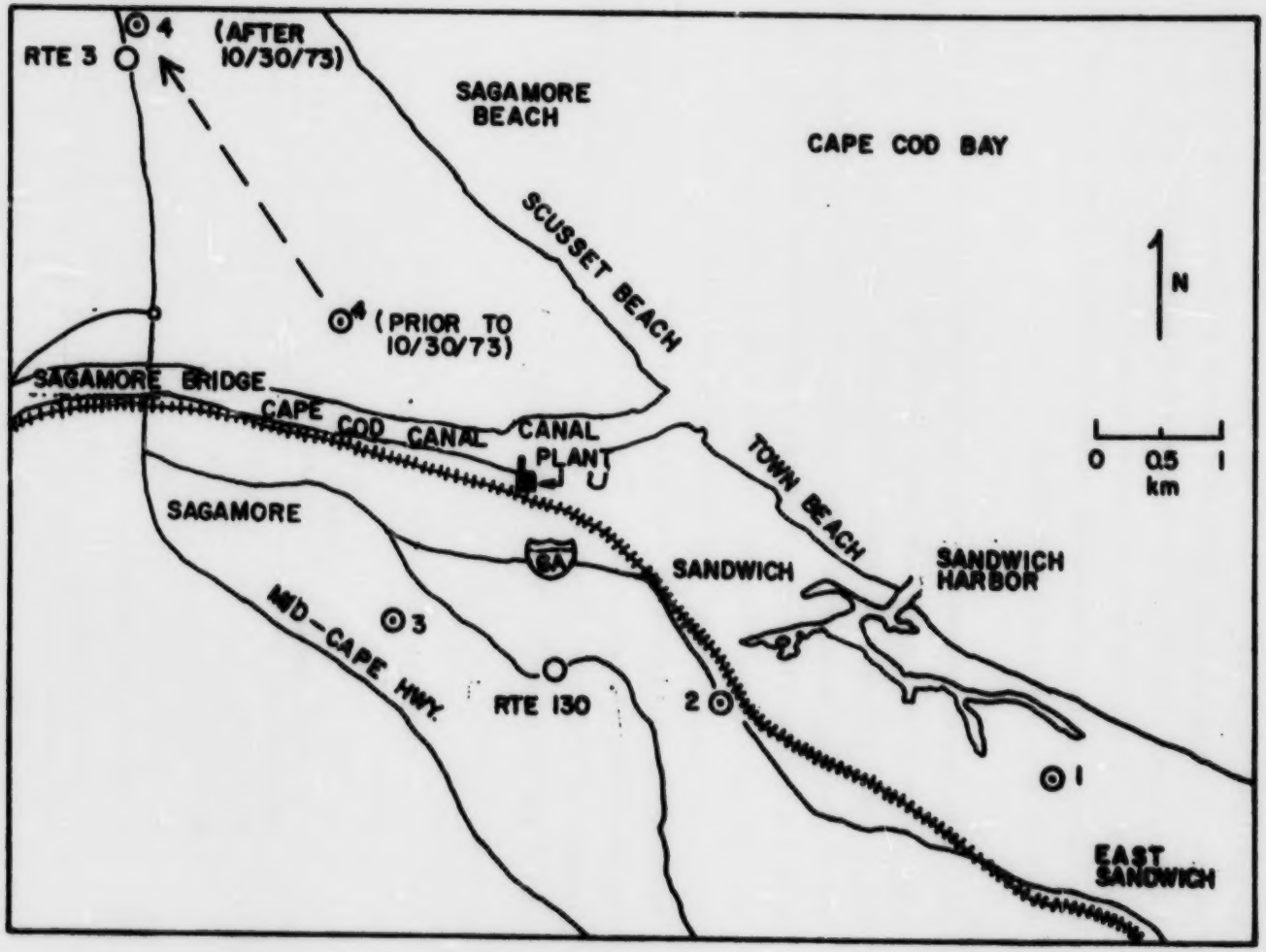

Figure 2. Sketch of the Canal Plant area showing the locations of the four automatic SO_2 stations by the symbol ⊙

Data for the 3-year period from 1 January 1971 to 31 December 1973 were selected for analysis in the present study. During this period, two changes in the allowable sulfur content of fuel burned at the Plant were made by the Massachusetts Department of Public Health. Also, the period included two extended periods when the Canal Plant was not in operation; these periods are useful in showing the contributions of other sources to the air quality in the vicinity of the Plant.

Bendix-Friez Aerovanes were used to provide local wind speed and direction data. Through July 1971, the principal source of wind data was the Aerovane mounted on a 12.2 meter mast located on the 58.8 m boiler-room roof. After July 1971, wind data were obtained from a second Aerovane installed on a 44 m tower near the top of Telegraph Hill approximately 3 miles from the Canal Plant in a south-southeasterly direction.

Climatology

The Canal Plant site experiences the large diurnal and seasonal changes in wind direction typical of coastal areas in southern New England. Figure 3, which gives frequency distributions of wind direction for the winter and summer months of 1971, illustrates the shift from prevailing westerly winds (SW through NW) in winter to predominantly southwesterly winds in the summer. Westerly winds are predominant during both seasons at night. Under light gradient winds, a northeasterly morning seabreeze frequently develops, particularly in the summer season. By midafternoon the wind has usually shifted to the southwest and increased in speed. Strong northeasterly winds may occur at any time during the passage of coastal storms.

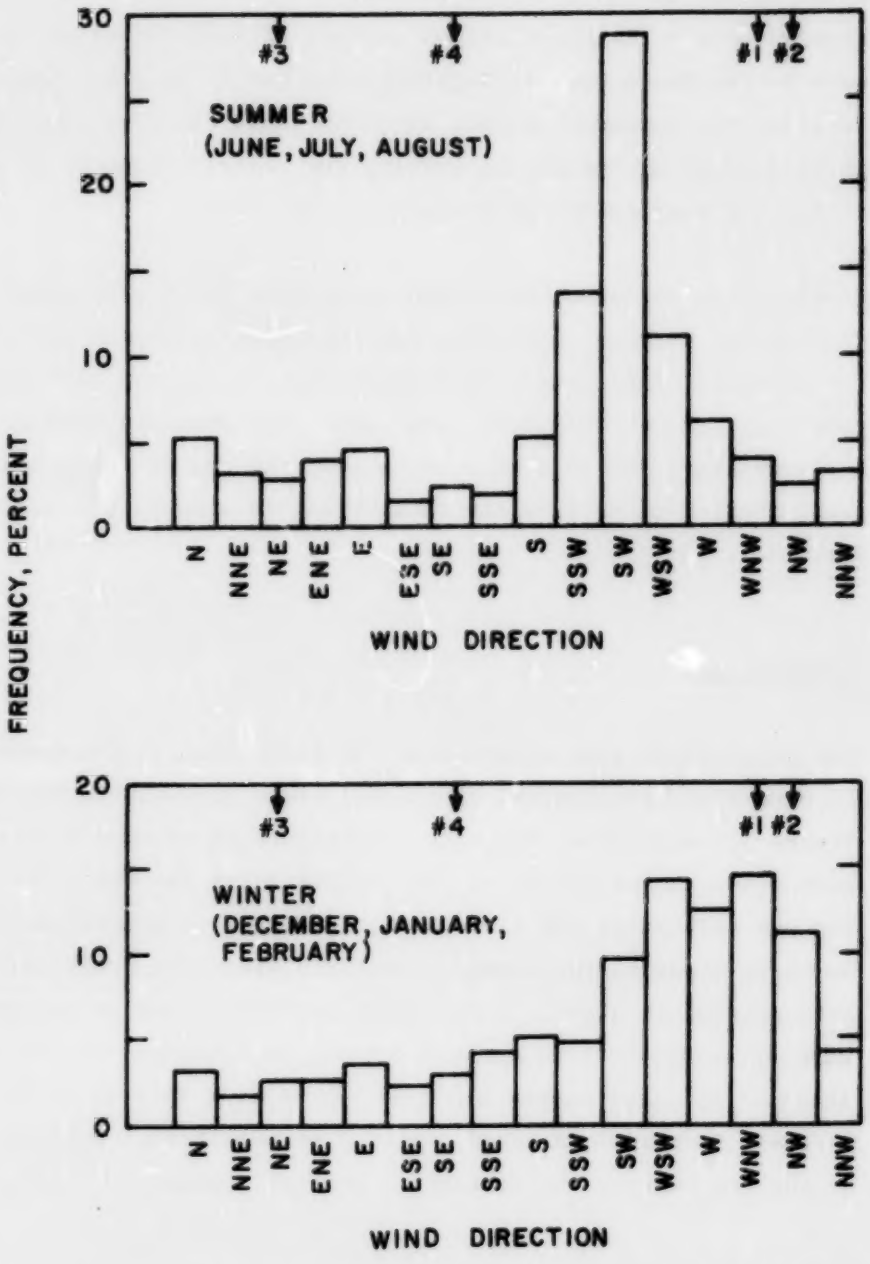

Figure 3. Seasonal wind direction distributions at Canal Plant in 1971 - arrows give directions when indicated SO_2 monitor is downwind

Although no effort has been made in the model calculations presented later to modify plume expansion rates to account for coastal influence a qualitative discussion of its effect on σ_A the standard deviation of azimuth wind direction follows. These estimates of σ_A were made from azimuth vane range data. As would be expected, the smallest observed values of σ_A, about 5 degrees, occur when the wind fetch is over Cape Cod Bay. With southeasterly winds, the median value of σ_A is about 7 or 8 degrees, except during the period from 1200 to 1600 local time when the effect of solar heating over Cape Cod is greatest. During this period, the median values of σ_A are 11 to 12 degrees. Somewhat large σ_A values occur during the daytime when the wind is from the mainland or from the south.

SECTION II

THE DATA BASE

Canal Plant data tapes containing plant parameters, meteorological data and ambient SO_2 measurements were made available for this study. A brief summary of the data on these tapes follows:

1. Plant Parameters

   The following plant operational data were given on an hourly basis:

   - Ambient air temperature
   - Stack gas temperature
   - Fuel assay (percent sulfur)
   - Fuel consumption
   - Gross operating load

2. Meteorological Data

   Meteorological data comprised the following hourly wind information covering the 10-minute period ending on the hour:

   - Average wind speed
   - Average wind direction
   - Maximum deflection of the wind direction pen
   - Minimum deflection of the wind direction pen

   This information was obtained by digitizing the wind chart records from the plant-operated Bendix Friez instruments. Hourly ambient dewpoint temperatures observed at Otis Air Force Base approximately 8 miles to the south of the Canal Plant were also included on the tape.

3. Ambient SO_2 Concentrations

The SO_2 concentration data comprised 30-minute average concentrations for each of the four principal monitoring stations.

In addition to the preceding data supplied by the Canal Plant, EPA provided the Federal Power Commission Form 67, from which generally available source data could be abstracted, and the following meteorological data sets from government operated meteorological stations:

- 1964 surface observations from Quonset Point Naval Air Station, Rhode Island
- 1964 radiosonde observations from Nantucket Island, Massachusetts
- 1971 surface and radiosonde observations from Quonset Point Naval Air Station, Rhode Island

Figure 1 shows the location of Quonset Point and Nantucket Island.

SECTION III

DATA PREPARATION AND REDUCTION METHODS

The data processing effort was carried out with two objectives in mind. The first was the transformation of 30-minute SO_2 concentration data into a form useful for the analysis of peak 1 hour to average 3 hour (1 to 3 hour) and peak 1 hour to average 24 hour (1 to 24 hour) concentration ratio distributions. The second aim was the construction of source, meteorological, and concentration data bases for use in the various model validation studies. We shall first examine the procedures required in the determination of ratio distributions.

DATA ANALYSIS REQUIRED FOR THE DEVELOPMENT OF TIME-CONCENTRATION RELATIONSHIPS

The measurements from the Canal Plant sampling and meteorological network described in the previous section were punched on cards which were subsequently read onto a magnetic tape. Two sets of data were employed in the study of time-concentration relationships. The first set consisted of 1971 SO_2 concentrations, meteorological data, and plant operating characteristics. These data were also used in the model validation study. The remainder of the data which was received later in the study covered the years 1972 and 1973 plus the last 2 months of 1970. Although these two data sets were initially analyzed separately, the calculated distributions were combined for the final presentation of the data. Concentration calibration factors, concentration measurements and plant operating parameters, wind direction data and wind speed data were arranged in separate tape files for a given month so that data entries for a particular hour were not in order. If the data were processed

in this format a large number of input/output actuations would have been required. This meant that the plant data had to be sorted so that all hourly parameters appeared in consecutive records. An example of this reformatted data is shown in Table 2. In this new data set we included only the average wind direction and omitted the maximum and minimum values. In addition, the atmospheric stability index was included in column 80 of the wind speed record for the 1971 observations only. These stability indices were determined from 1971 Quonset Point hourly surface observations by means of an EPA preprocessor program which will be described in Section V.

The first step in the data reduction process was the application of calibration factors to 30-minute SO_2 concentrations for each of the four measurement sites. After multiplication by the appropriate calibration factors, half-hourly values of SO_2 background were calculated using those measurement stations which lay outside a 90-degree downwind sector. If one of the readings was missing (coded as 999), its contribution to the background determination was ignored. The SO_2 values for the stations outside the sector were then averaged and subtracted from each of the concentration measurements. The resultant calibrated and background corrected 30-minute SO_2 concentrations for each of the four stations were then written on tape along with the corresponding meteorological and source parameters for the hour. A sample listing of these corrected concentrations is given in Table 3.

The tape containing the corrected concentrations serves as input for two additional data analysis programs. The first of these programs simply averages the two 30-minute concentrations for each hour and writes hourly and daily concentrations on cards which are later read by a concentration bin sort routine that develops cumulative frequency distributions to be used in the model validation study. The second program computes a running set of peak 1 hour to average 3 hour

Table 2. UNCORRECTED PLANT DATA

CALIBRATION FACTORS

```
3  01  31  1.06
4  01  31  1.04
6  01  31  1.03
9  01  31  1.10
END
```

1st AND 2nd ½ HOUR CONCENTRATIONS (ppb)

FUEL CONSUMPTION (10^3 lbs/hr); % SULFUR x100; STACK TEMP (°F); TEMP (°F); GROSS LOAD (MW); DEW PT (°F)

```
010171 0100 53 015 014 44 024 020 66 016 015 99 013 011 228 257 032 306 676 0116
010171 0100  84  81  78   <- AVERAGE WIND DIRECTION (degrees)
010171 0100 069   <- WIND SPEED x 10 (mi/hr)                    STABILITY INDEX 4   7
                                                                                    8
010171 0200 53 011 015 44 024 015 66 019 018 99 014 012 228 234 032 299 531 0126
010171 0100  83  72  58                                                        4   7
010171 0200 109                                                                     8
010171 0300 53 013 009 44 016 024 66 016 009 99 008 005 228 235 037 303 529 0176
010171 0300  86  74  62                                                        4   7
010171 0300 132                                                                     8
010171 0400 53 006 006 44 012 012 66 006 005 99 002 003 228 234 036 288 529 0296
010171 0300  91  79  64                                                        4   7
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010171 1700 394                                                                     8
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Table 3. CORRECTED PLANT DATA

			½ HOUR CONCENTRATIONS (ppb) CALIBRATED AND CORRECTED FOR BACKGROUND													
1	171	100	-2	-1	7	5	-2	0	-4	-4	228	257	032	306	576	0116
			81													6
		69														
1	171	200	-6	1	8	1	2	4	-2	-2	228	234	032	299	531	0126
			72													4
		109														
1	171	300	1	0	4	5	3	-1	-4	-4	228	235	037	303	529	0176
			74													4
		132														
1	171	400	-1	-1	5	5	-1	-2	-5	-4	228	234	036	288	529	0296
			79													4
		136														
1	171	500	-3	-3	8	7	-4	-1	-5	-4	228	236	039	305	530	0216
			66													4
		191														
1	171	600	-2	-4	6	5	-4	-3	-3	-2	228	235	038	295	530	0236
			66													4
		234														
1	171	700	-3	-1	8	4	-5	-1	-4	-2	228	235	038	293	530	0236
			68													4
		274														
1	171	900	0	-2	3	3	0	-2	-2	-2	228	299	038	209	467	0236
			66													4
		259														
1	171	900	0	-3	3	7	-1	-2	-2	-4	228	222	036	295	461	0266
			57													4
		281														
1	171	1000	0	-2	3	6	-1	3	-2	-3	228	263	036	311	594	0266
			47													4
		285														
1	171	1100	-2	-1	6	3	14	18	-4	-3	228	222	036	305	527	0266
			43													4
		299														
1	171	1200	-1	-3	2	7	109	196	-2	-4	228	147	036	295	223	0266
			39													4
		326														
1	171	1300	-3	-1	7	2	244	314	-4	-2	228	150	036	295	320	0266
			39													4
		359														
1	171	1400	-1	-2	3	6	171	141	-2	-3	228	149	037	291	317	0276
			33													4
		393														
1	171	1500	-3	-1	7	5	144	111	-4	-3	228	167	038	290	361	0266
			36													4
		374														
1	171	1600	-2	-3	6	8	32	-3	-3	-5	228	193	036	298	426	0266
			16													4
		354														
1	171	1700	-2	4	6	3	-3	-7	-4	-7	228	240	036	301	533	0266
			6													4
		394														

and daily peak 1 hour to average 24 hour concentration ratios and writes these values on tape together with the date, time, source, and meteorological parameters for the peak hour. For the calculation of the 1 to 3 hour ratios, three hour intervals were allowed to overlap, giving a new ratio for each hour. In the case of the 1 to 24 hour ratios, however, only one ratio was evaluated for each calendar day. If one of the hourly concentrations to be used in a 3 hour or 24 hour average was missing, then the ratio is flagged as 999 so that it would be ignored by the ratio bin sort routine. Cases where the 3 hour or 24 hour average concentrations were zero were also flagged. Both 1 to 3 hour and 1 to 24 hour ratios were sorted into 50 bins to generate a frequency distribution. Separate ratio frequency distributions were constructed for different stability classes, seasons, wind speeds, wind directions, receptor locations, peak 1 hour concentrations, and hour of the day. Bin sorted ratio data for 1971 is presented in Appendix A. A detailed analysis of cumulative frequency distributions of ratios for all of the plant data on hand will be presented in Section IV along with correlation coefficients between peak 1 hour concentrations and associated 1 to 3 hour and 1 to 24 hour concentration ratios.

PREPARATION OF INPUT TO THE SINGLE SOURCE DIFFUSION MODEL

The discussion of model inputs will be broken down into a treatment of meteorological and source data base combinations for 4 different model validation runs. Since 1964 was the last year for which hourly (rather than 3 hourly) surface meteorological data was tabulated for many weather stations, an initial model run was carried out using 1964 Quonset Point, Rhode Island (station 14788) surface data (wind speed, wind direction, and total cloud cover) and 1964 Nantucket, Massachusetts daily mixing depths (morning and afternoon). For this run source data including monthly averages of fuel consumption and percent sulfur, stack gas temperature, gas velocity and stack radius were taken from FPC Form 67 for the year 1971. The details of the conversion of FPC data to model input format are given in Appendix B.

Since hourly surface data for 1971 was available from the Quonset Point station, it was decided to undertake a second model run using the same FPC source data, but using the 1971 meteorological data. The mixing depths for this case were also taken from Quonset Point.

For a more detailed check of the Single Source Model two more runs were made incorporating an increasing degree of input data resolution. The first run used the 1971 meteorological data employed in the previous run but utilized the plant data tape by means of a program which calculates average monthly and diurnal variations of plant SO_2 emissions. These monthly and diurnal variations are likely to be the most detailed source information for many facilities for which the Single Source Model would be applied.

The fourth model run utilized actual SO_2 hourly source strengths dumped on cards from the plant data tape. The meteorological input data for this validation exercise was a combination of 1971 Plant measurements and 1971 Quonset Point surface and upper air data. The composite data set contained wind speed, wind direction, and temperature data from the plant and hourly atmospheric stabilities and mixing depths from the Quonset Point station. A summary of the data bases used in the model validation runs is given in Table 4.

These different model validation cases required several programming changes in the models themselves. Originally EPA provided us with both the seasonal and diurnal versions of the Single Source Model. Since these models were designed for leap year (1964) calculations a small modification was made so that the program would accept 1971 meteorological data. The model also had the option for input of an average elevation difference between stack base and surrounding terrain. In all of our validation runs we provided for a separate source-receptor elevation difference to be input for each receptor range.

For model run 4 the code had to be modified so that it would accept hourly SO_2 emission data. Also, for this last run we had to make provision for a wind speed instrument height greater than 7 meters.

Table 4. DATA BASES FOR MODEL VALIDATION RUNS

Model run	Meteorological data base	Source data base
1	1964 Quonset Point surface observations and 1964 Nantucket mixing depths	Form FPC-67
2	1971 Quonset Point surface and mixing depth observations	Form FPC-67
3	1971 Quonset Point surface and mixing depth observations	Summary of plant source data with monthly and diurnal variations specified
4	Combination of plant and Quonset Point surface observations with Quonset Point mixing depth data	Actual hourly plant SO_2 emissions

SECTION IV

ANALYSIS OF CONCENTRATION RATIO DISTRIBUTIONS

The first task in our analysis of the concentration ratio distributions was to determine whether these distributions would conform to standard types such as normal or log-normal. From the outset it was realized that there would be difficulty in describing the ratio distributions in terms of standard types since the range of ratios is bounded. For example, a peak 1 hour to average 3 hour ratio must be equal to or greater than 1 and less than or equal to 3. Another complication arises from the fact that the original concentration values were recorded as integers. Therefore, for the case or rather low concentrations the ratio distributions are likely to be quite discrete in nature. This may be seen from the following exercise in which peak 1 hour to average 3 hour concentration ratios were generated from random concentrations. For this calculation, 30 minute concentrations were generated randomly in an interval between 0 $\mu g/m^3$ and two upper bounds of 10 $\mu g/m^3$ to 100 $\mu g/m^3$. The routine chosen for the random number generation produces a uniform distribution of floating point numbers between 0.0 and 1.0. Figure 4 shows how the ratio distribution becomes smoother for the larger upper bound. Since ground level concentrations due to point source emissions are more likely to follow a log-normal probability distribution there will be a large number of low concentrations so that the resultant ratio distribution will be discrete. This conclusion is borne out by an examination of the peak 1 hour to average 3 hour ratio distributions given in Appendix A. The peak 1 hour to average 24 hour ratio distributions show the same discrete nature but to a lesser degree than for the peak 1 hour to average 3 hour distributions. If we restrict ourselves to those ratios for which the peak 1 hour concentrations occur when the wind was blowing within 20 degrees of the station, thereby insuring

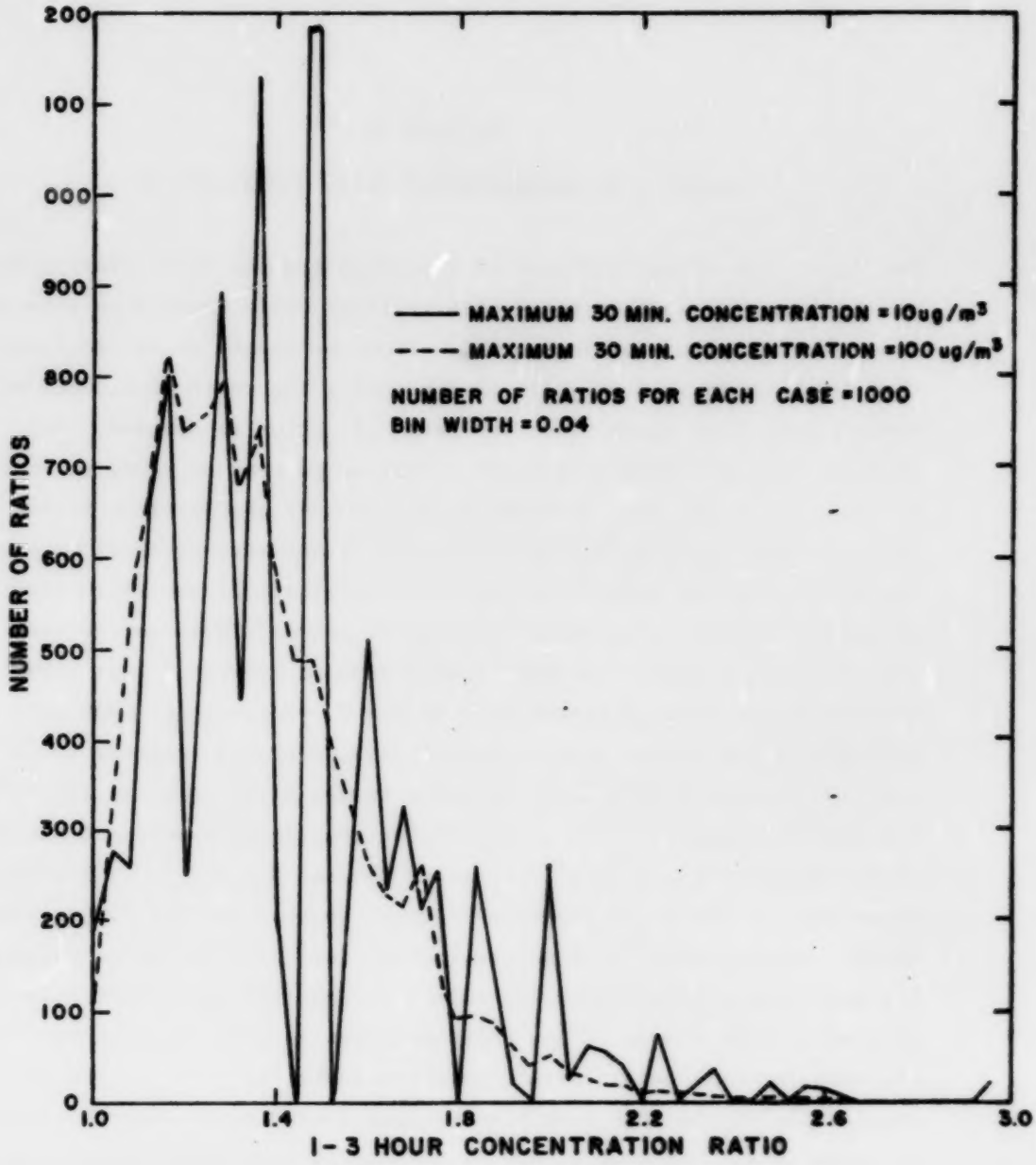

Figure 4. 1-hour to 3-hour ratio distributions generated from random interger concentrations

a greater proportion of higher concentrations, we find that the ratio distributions become smoother. This can be seen if we examine the appropriate peak 1 hour to average 3 hour distributions shown in Appendix A.

In spite of the difficulties just mentioned, it was decided to proceed with our comparison of ratio distributions with the standard types. Figures 5 and 6 show peak 1 hour to average 3 hour and peak 1 hour to average 24 hour concentration ratio cumulative frequency distributions on linear probability and log probability scales respectively. Figures 7 and 8 show the same distributions with the data restricted to downwind stations. An examination of these curves indicates that the log-normal distribution is a more appropriate description for both 1 to 3 hour and 1 to 24 hour ratio distributions. Table 5 presents a list of relevant distribution parameters such as maximum, minimum, mean, standard deviation, 95th and 99th percentiles. Data is also presented for the case in which the wind was blowing within 20 degrees of the station heading.

An inspection of Table 5 reveals a significant difference between distribution parameters for the case in which all data was used as opposed to the distribution obtained when only data from downwind stations was utilized. For both 1 to 3 hour and 1 to 24 hour ratio distributions there is a definite trend toward higher mean, 50, 95, and 99 percentile values for the case in which ratio calculations were restricted to downwind stations. At the same time the standard deviations for the downwind distributions were definitely smaller. This feature is the result of having fewer extreme ratio values due to higher concentrations downwind. The fraction of time a particular station is downwind of the plant is given in Table 6.

The second part of our study of concentration ratio distributions was devoted to an understanding of how the distributions were affected by factors such as wind speed, season, stability, and hour of the day. The cumulative frequency distributions of concentration ratios were constructed from the entire data base used in the study.

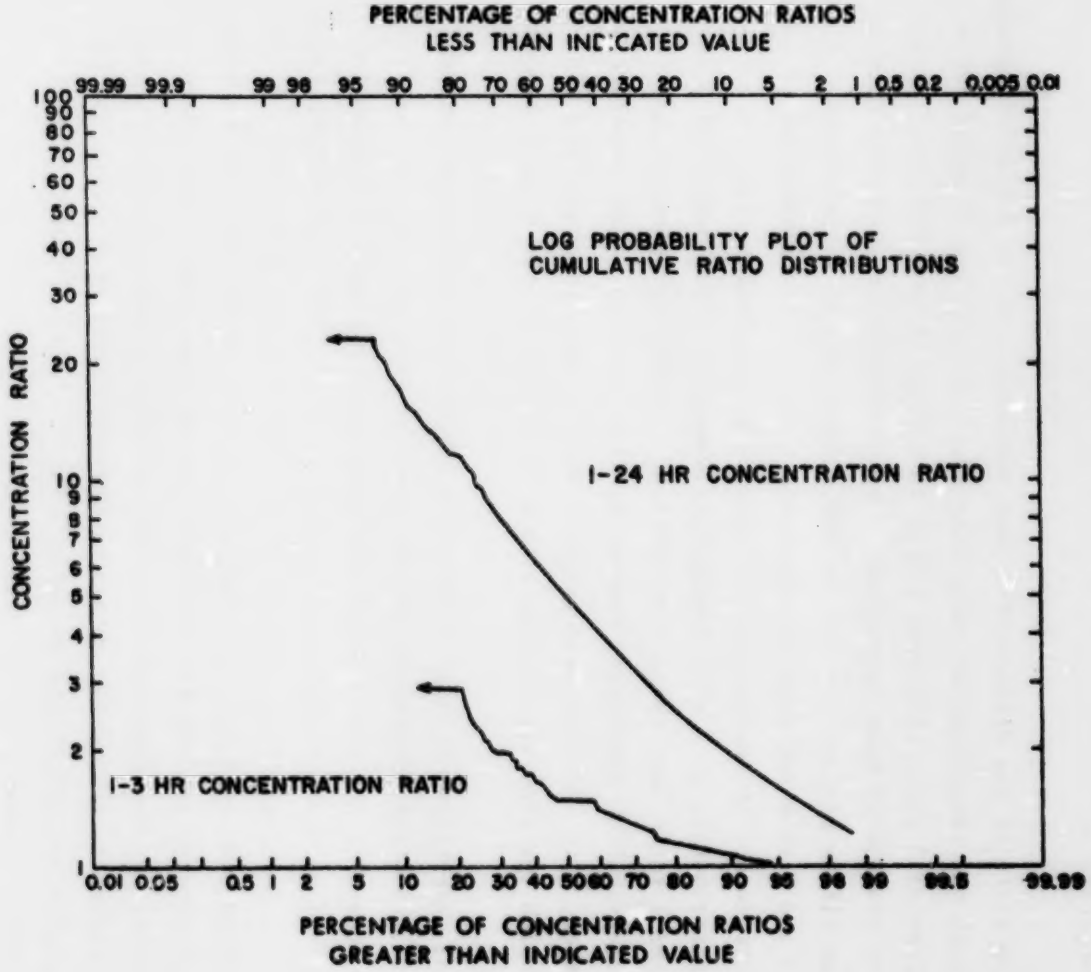
PERCENTAGE OF CONCENTRATION RATIOS
LESS THAN INDICATED VALUE
99.99 99.9 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.005 0.01
LOG PROBABILITY PLOT OF
CUMULATIVE RATIO DISTRIBUTIONS
1-24 HR CONCENTRATION RATIO
1-3 HR CONCENTRATION RATIO
CONCENTRATION RATIO
100 90 80 70 60 50 40 30 20 10 9 8 7 6 5 4 3 2 1
0.01 0.05 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.99
PERCENTAGE OF CONCENTRATION RATIOS
GREATER THAN INDICATED VALUE

Figure 5. Log probability plots of cumulative ratio distributions

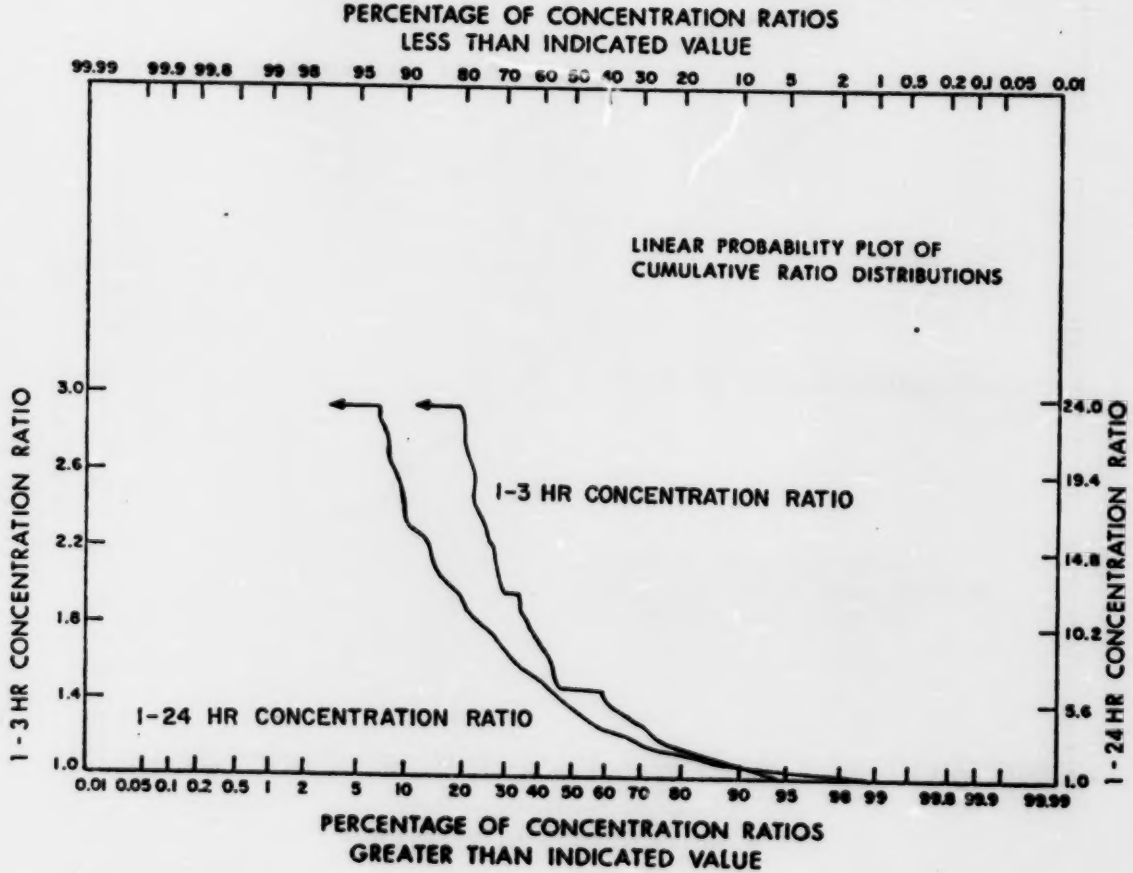
PERCENTAGE OF CONCENTRATION RATIOS
LESS THAN INDICATED VALUE
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
LINEAR PROBABILITY PLOT OF
CUMULATIVE RATIO DISTRIBUTIONS
1-3 HR CONCENTRATION RATIO
1-24 HR CONCENTRATION RATIO
1-3 HR CONCENTRATION RATIO
3.0
2.6
2.2
1.8
1.4
1.0
1-24 HR CONCENTRATION RATIO
24.0
19.4
14.8
10.2
5.6
1.0
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
PERCENTAGE OF CONCENTRATION RATIOS
GREATER THAN INDICATED VALUE

Figure 6. Linear probability plots of cumulative ratio distributions

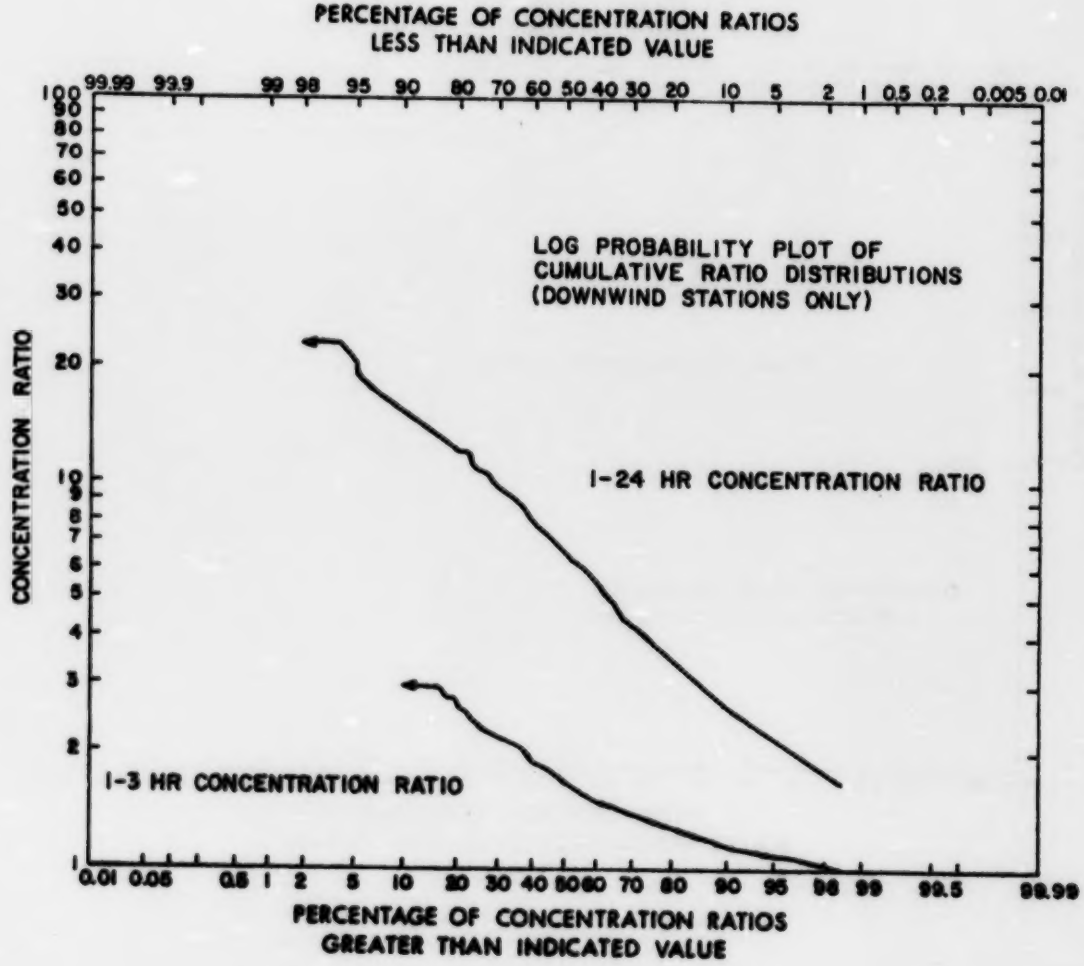
PERCENTAGE OF CONCENTRATION RATIOS
LESS THAN INDICATED VALUE
99.99 99.9 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.005 0.01
CONCENTRATION RATIO
LOG PROBABILITY PLOT OF
CUMULATIVE RATIO DISTRIBUTIONS
(DOWNWIND STATIONS ONLY)
1-24 HR CONCENTRATION RATIO
1-3 HR CONCENTRATION RATIO
0.01 0.05 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.99
PERCENTAGE OF CONCENTRATION RATIOS
GREATER THAN INDICATED VALUE

Figure 7. Log probability plot by cumulative ratio distributions (downwind stations only)

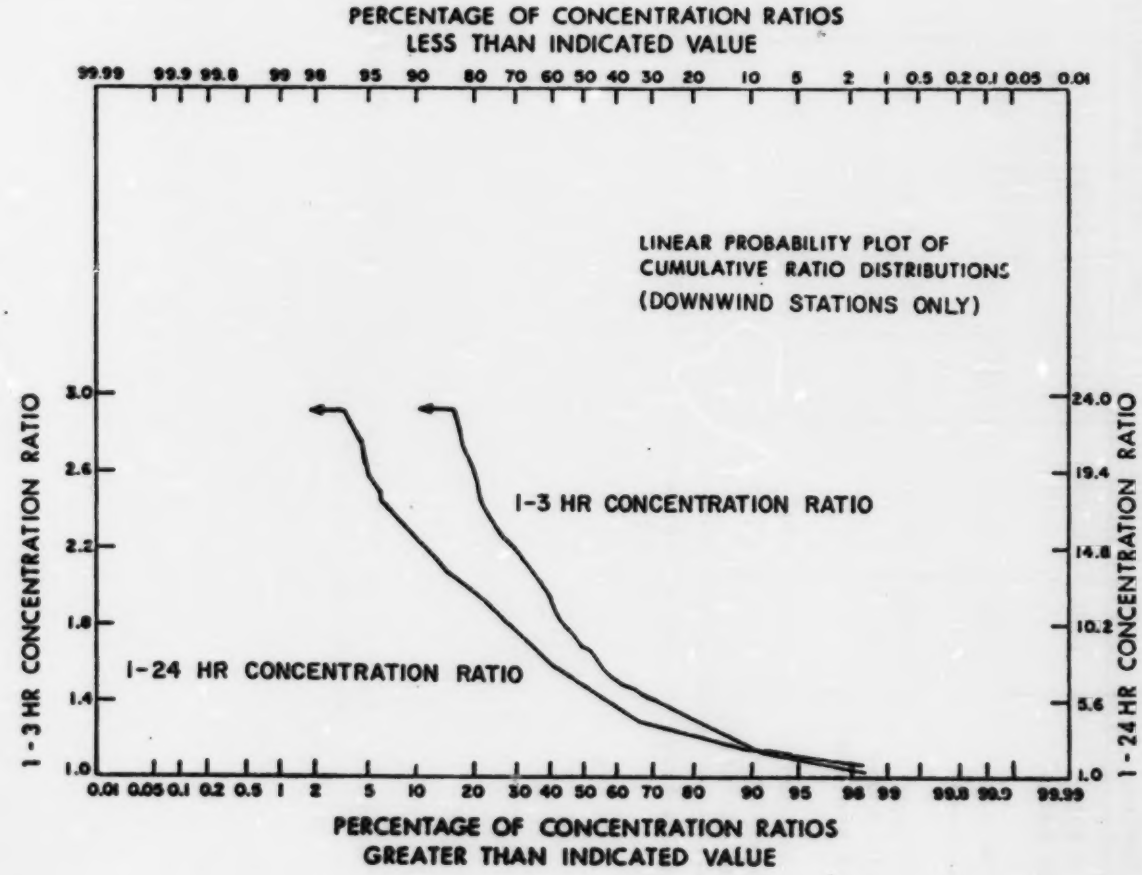
PERCENTAGE OF CONCENTRATION RATIOS
LESS THAN INDICATED VALUE
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
LINEAR PROBABILITY PLOT OF
CUMULATIVE RATIO DISTRIBUTIONS
(DOWNWIND STATIONS ONLY)
1-3 HR CONCENTRATION RATIO
1-24 HR CONCENTRATION RATIO
3.0
2.6
2.2
1.8
1.4
1.0
24.0
19.4
14.8
10.2
5.6
1.0
1-3 HR CONCENTRATION RATIO
1-24 HR CONCENTRATION RATIO
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
PERCENTAGE OF CONCENTRATION RATIOS
GREATER THAN INDICATED VALUE

Figure 8. Linear probability plot of cumulative ratio distributions (downwind stations only)

Table 5. STATISTICS FOR RATIO DISTRIBUTIONS[a]

Ratios	Mean	Standard deviation	50%	95%	99%	Maximum	Minimum
1 to 3 hour (all data)	1.81	0.70	1.50	1.02	1.02	3	1
1 to 24 hour (all data)	7.84	6.31	5.37	1.69	1.23	24	1
1 to 3 hour (only down-wind stations)	1.90	0.65	1.66	1.10	1.02	3	1
1 to 24 hour (only down-wind stations)	8.54	5.63	6.75	2.15	1.69	24	1

[a]Given in terms of cumulative percent of ratios greater than given values

Table 6. PERCENT OF TIME FLOW VECTOR IS WITHIN 20 DEGREES OF A MEASUREMENT STATION (1971 DATA)

Station	Percent
1	14
2	11
3	7
4	5

Rather than examining the entire distribution to discover the influence of these factors, it was decided to study the variation of the 50 percentile values of the distribution with different values of a given parameter.

In the first of these studies we set out to find what relationship exists between the concentration ratio distributions and the peak 1 hour concentrations themselves. Figure 9 shows a plot of 50 percentile values for 1 to 3 hour and 1 to 24 hour concentration ratios as a function of peak 1 hour concentration. The peak in 50 percentile values for low concentrations is due to the discrete nature of the measured concentrations discussed earlier. For example, it is not unusual to have a low concentration of 1 or 2 $\mu g/m^3$ giving a peak 1 hour to average 3 hour ratio of 3. Another interesting feature of this plot is that the 1 to 3 hour and 1 to 24 hour data are quite similar in shape. The correlation coefficient between peak 1 hour concentration and 1 to 3 hour and 1 to 24 hour concentration ratio were found to be -0.017 and -0.008 respectively. The data used for the calculation of these correlation coefficients did not contain the 1971 concentrations. Besides a general rise in 50 percentile ratios with increasing peak 1 hour concentration, the other dominant features are two peaks in 52 to 60 $\mu g/m^3$ range which occur for both 1 to 3 hour and 1 to 24 hour distributions. While both of the 1 to 3 hour 50 percentile peaks could be significant, the 1 to 24 hour peaks only represent total bin counts of 8 and 6 respectively.

If the 50 percentile ratio values are plotted as a function of windspeed as in Figure 10, we find that there is a slight tendency for higher ratios during periods of light winds. This is reasonable since during light winds the wind vector would be more variable, leading to elevated concentrations for short periods of time. The trend is evident in both 1 to 3 hour and 1 to 24 hour ratios.

A related phenomenon is evident for the 1 to 3 hour case when the 50 percentile ratios are displayed (Figure 11) as a function of atmospheric stability index. Fifty percentile values of 1 to 3 hour ratios

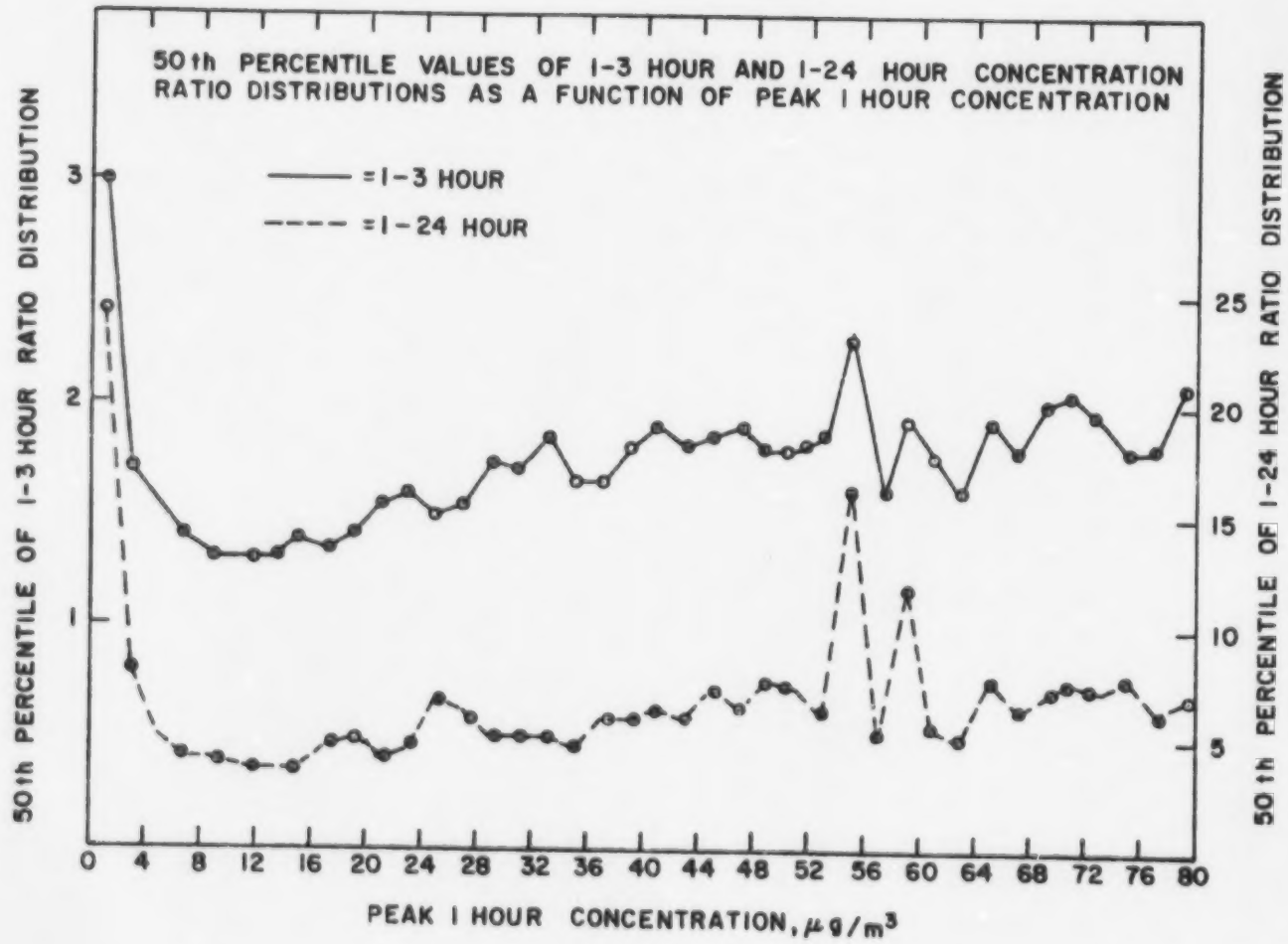
50th PERCENTILE VALUES OF 1-3 HOUR AND 1-24 HOUR CONCENTRATION RATIO DISTRIBUTIONS AS A FUNCTION OF PEAK 1 HOUR CONCENTRATION
=1-3 HOUR
=1-24 HOUR
50th PERCENTILE OF 1-3 HOUR RATIO DISTRIBUTION
50th PERCENTILE OF 1-24 HOUR RATIO DISTRIBUTION
PEAK 1 HOUR CONCENTRATION, μg/m³
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64 68 72 76 80
1 2 3
5 10 15 20 25

Figure 9. Fifty percentile values of ratio distributions as a function of peak 1-hour concentration

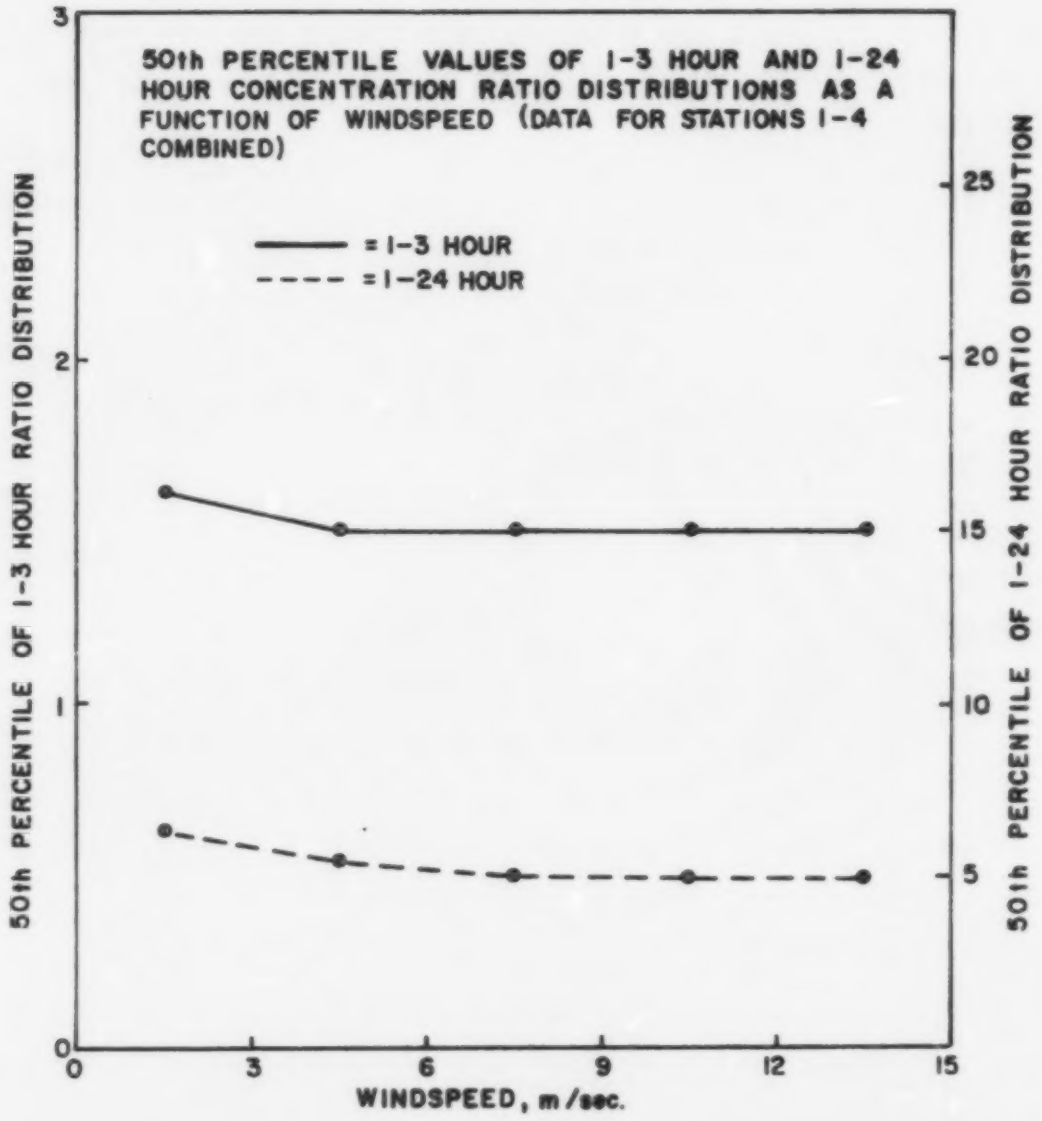

Figure 10. Fifty percentile values of ratio distributions for different wind speeds

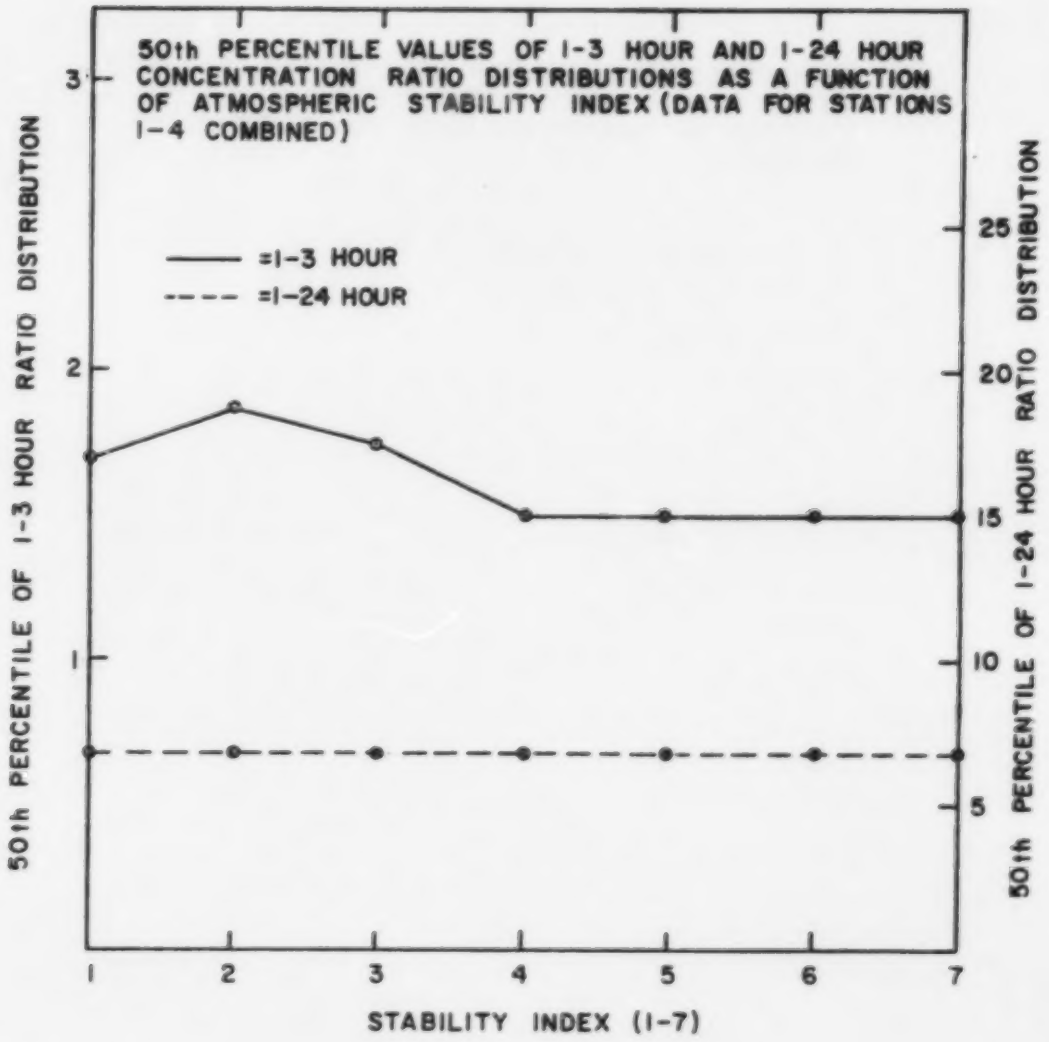

Figure 11. Fifty percentile values of ratio distribution for different stability indices

for stabilities 1 through 3 are some 15 percent higher than the values for stabilities 4 through 7. These lower stability indicies are associated with more unstable atmospheric conditions due to light winds, sparse cloud cover, and maximum solar insolation. Since these conditions rarely persist more than a few hours in any day, it is not surprising that the stability dependence is not reflected in the 1 to 24 hour ratio distribution. These 50 percentile curves were constructed with 1971 plant data only. The effect of stability upon concentration ratios may also be seen indirectly in Figure 12 in which 50 percentile ratios are shown for different hours of the day. The highest ratios are seen at midday during the period at which the most unstable conditions would be expected to occur.

While time of day, stability, and wind speed are seen to exert an influence upon the ratio distributions, Figures 13 and 14 show that the 50th percentile values are at most only weakly related to receptor distance from the source and time of year. There is, however, a slight indication that both 1 to 3 hour and 1 to 24 hour ratios might be higher close to the source. The explanation for this decrease in concentration ratio with distance from the source may be found in Gifford's[6] treatment of a fluctuating plume model.

When the 50 percentile values of the ratio distributions for 1971 were compared with those for the combined 1972 - 1973 data set the 1971 values were higher for 1 to 3 hour ratios and 1 to 24 hour ratios by 5 percent and 12 percent respectively.

The ratio sensitivity analysis just described was also carried out for the case in which the concentration ratios were restricted to those for which the wind flow vector during the peak hour was within 20 degrees of a measurement station (Figures 15 through 19). Due to the rather limited amount of data available after this downwind restriction was made, the following sensitivity plots were not presented: (1) variations with stability for both 1 to 3 hour and 1 to 24 hour ratios and (2) 1 to 24 hour ratio variations with peak 1 hour concentrations.

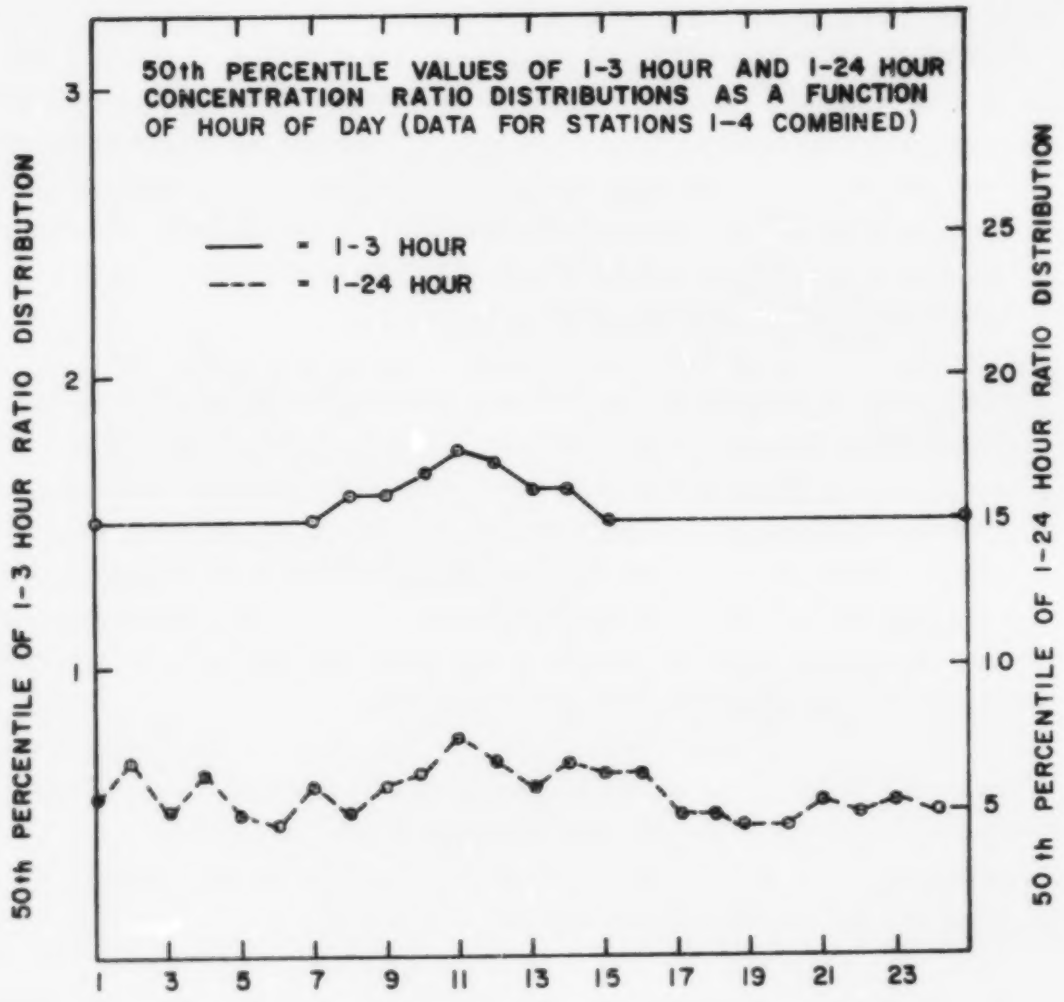

Figure 12. Fifty percentile values of ratio distributions for each hour of the day

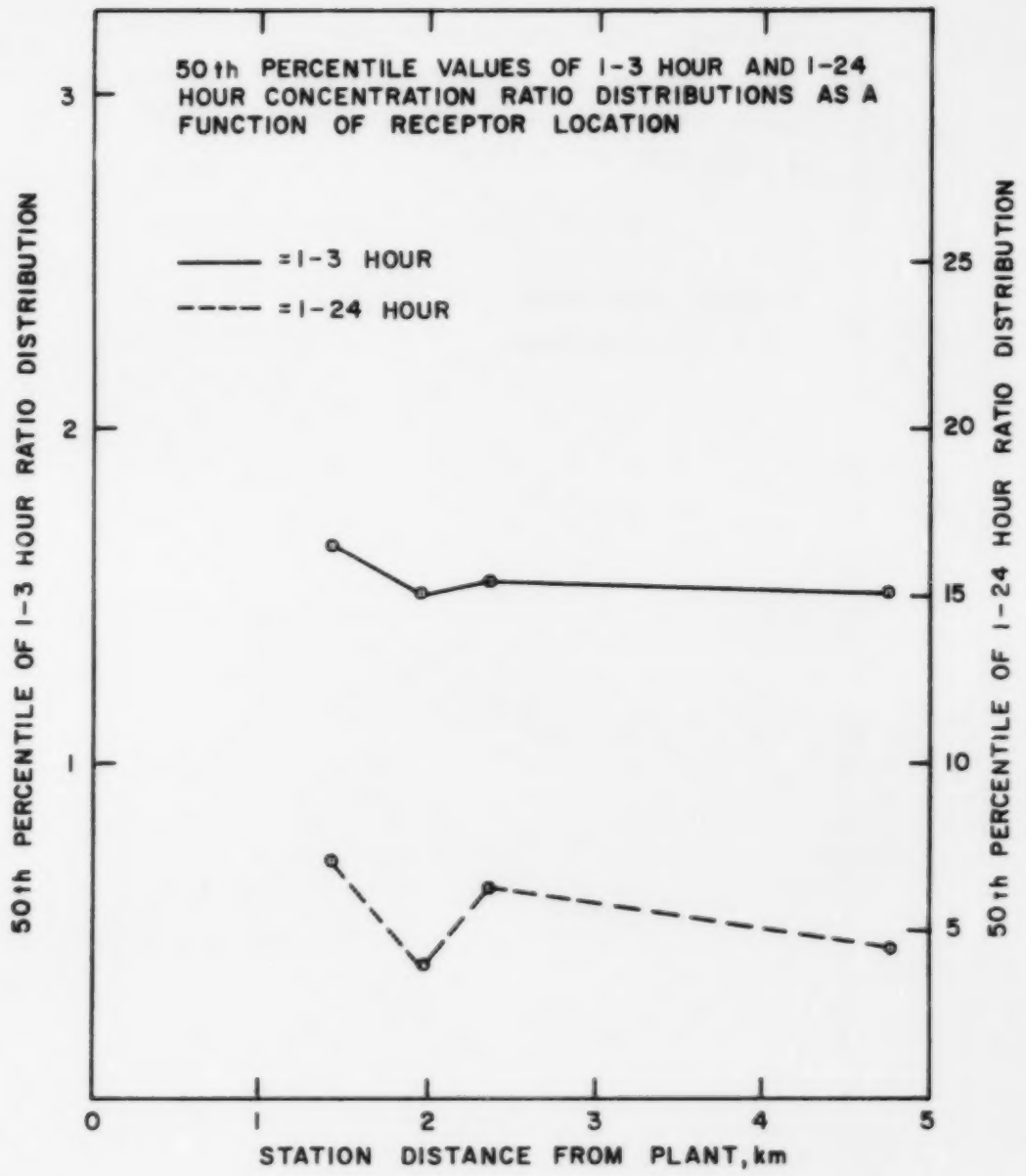

Figure 13. Fifty percentile values of ratio distributions for different distances from the plant

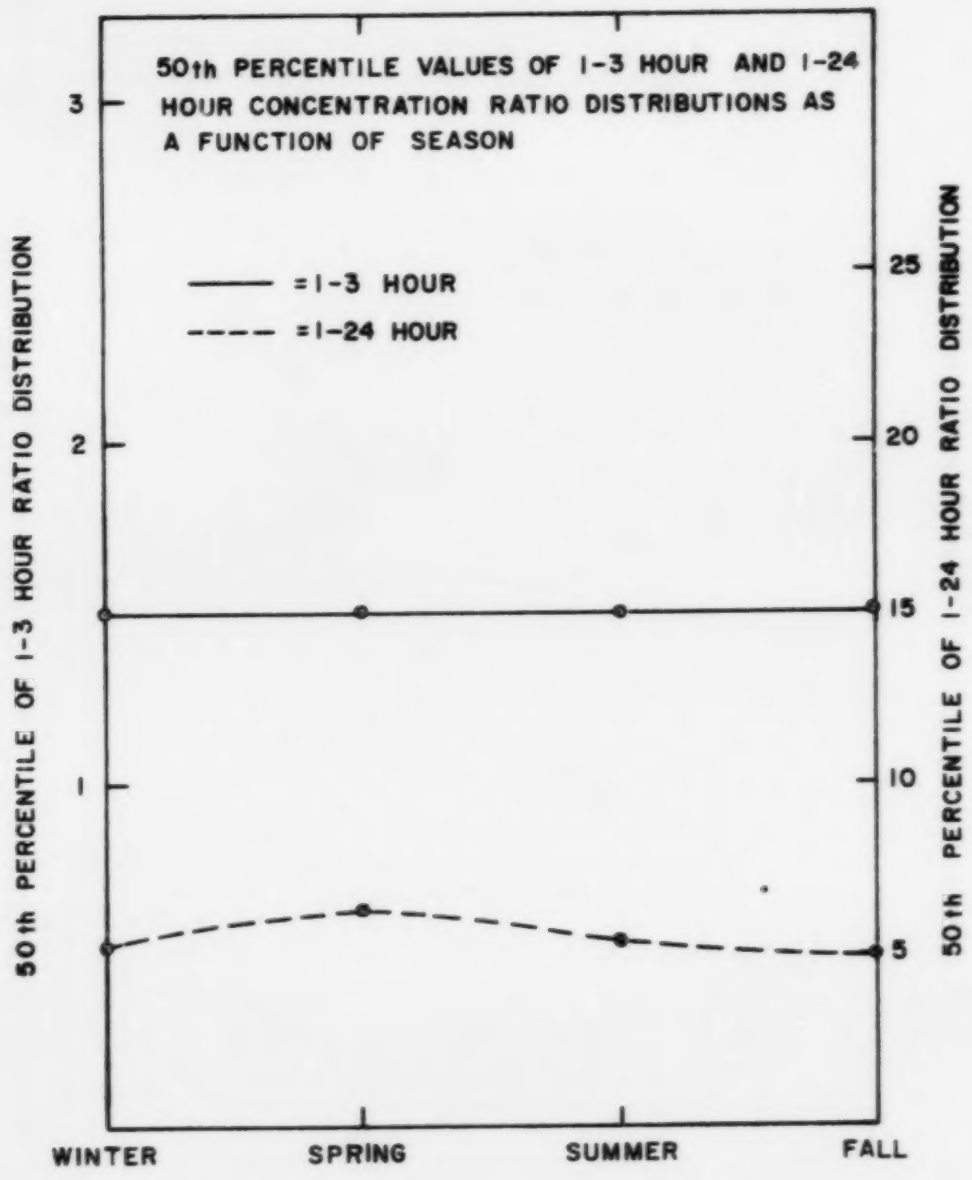

Figure 14. Fifty percentile values of ratio distributions for different seasons.

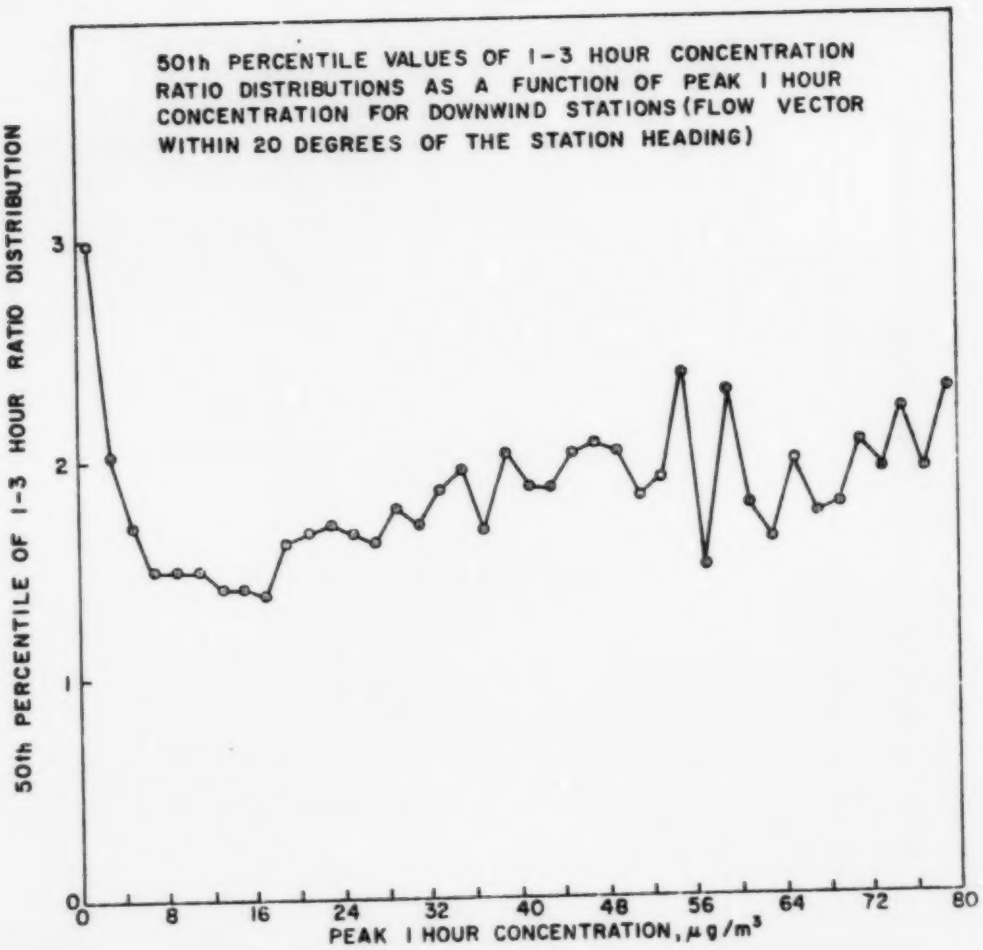

Figure 15. Fifty percentile values of 1 to 3 hour concentration ratio distributions as a function of peak 1 hour concentration for downwind stations

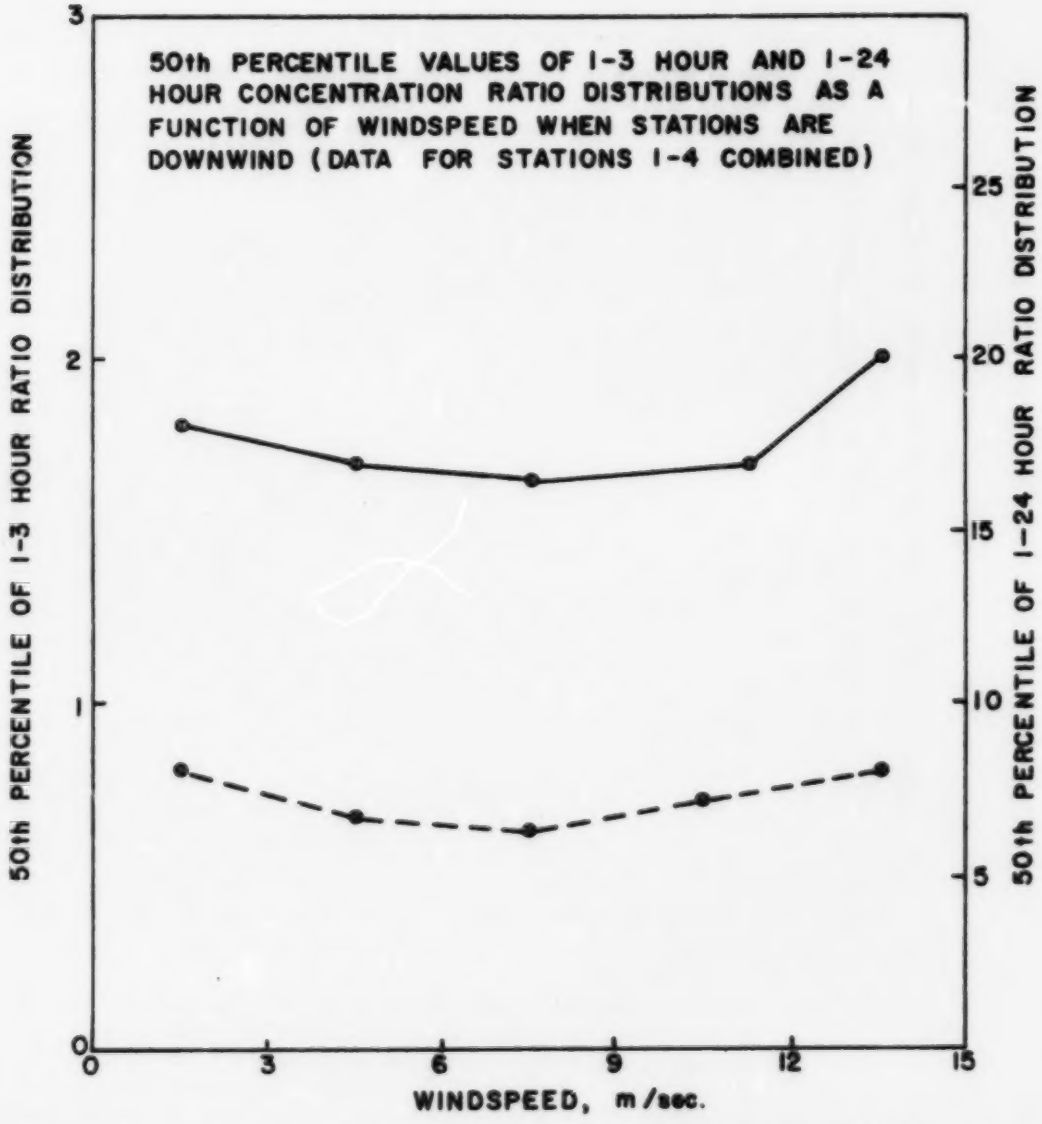

Figure 16. Fifty percentile values of 1 to 3 hour and 1 to 24 hour concentration ratio distributions as a function of windspeed when stations are downwind

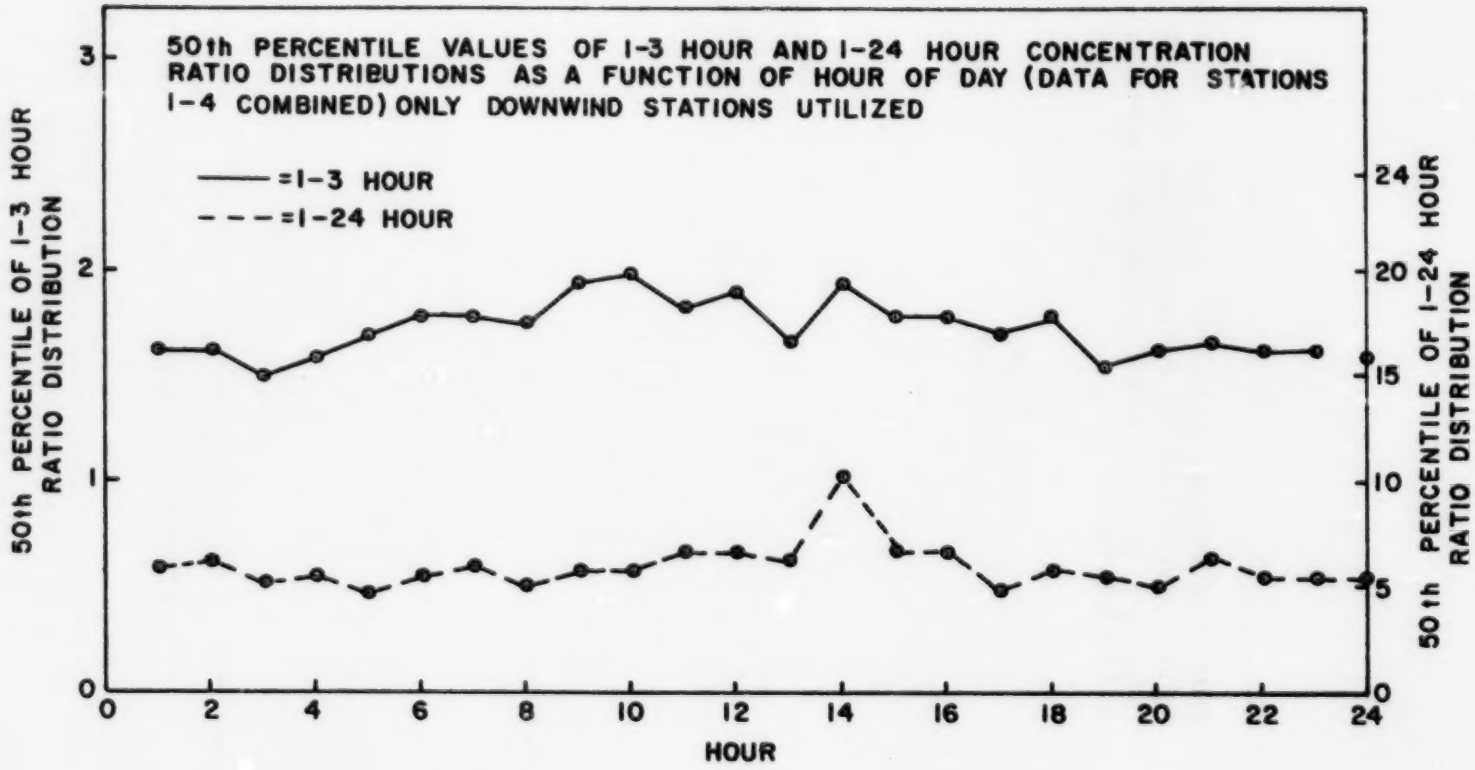

Figure 17. Fifty percentile values of 1 to 3 hour and 1 to 24 hour concentration ratio distributions as a function of hour of the day. Only downwind stations utilized

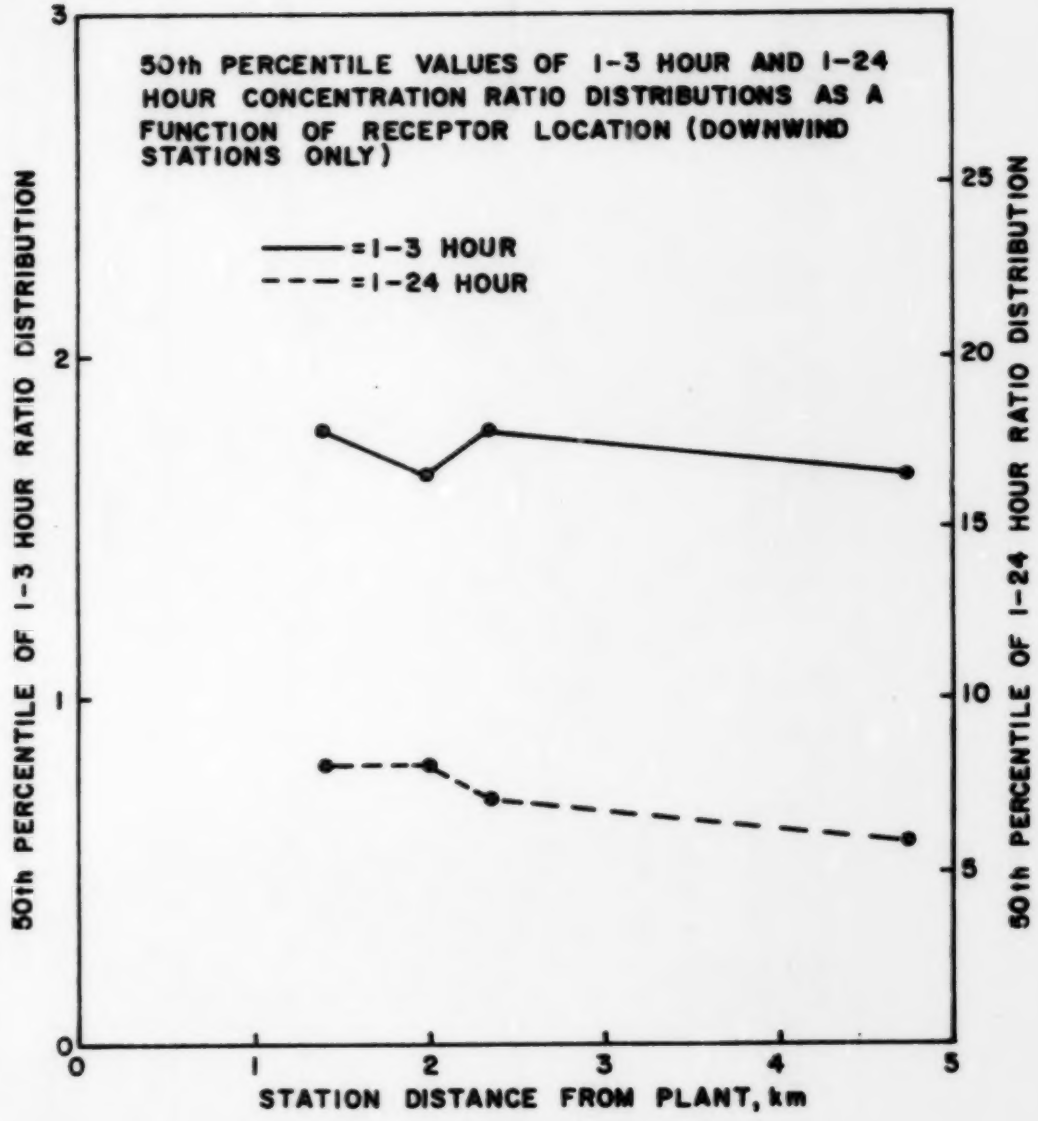

Figure 18. Fifty percentile values of 1 to 3 hour and 1 to 24 hour concentration ratio distributions as a function of receptor location for downwind stations only

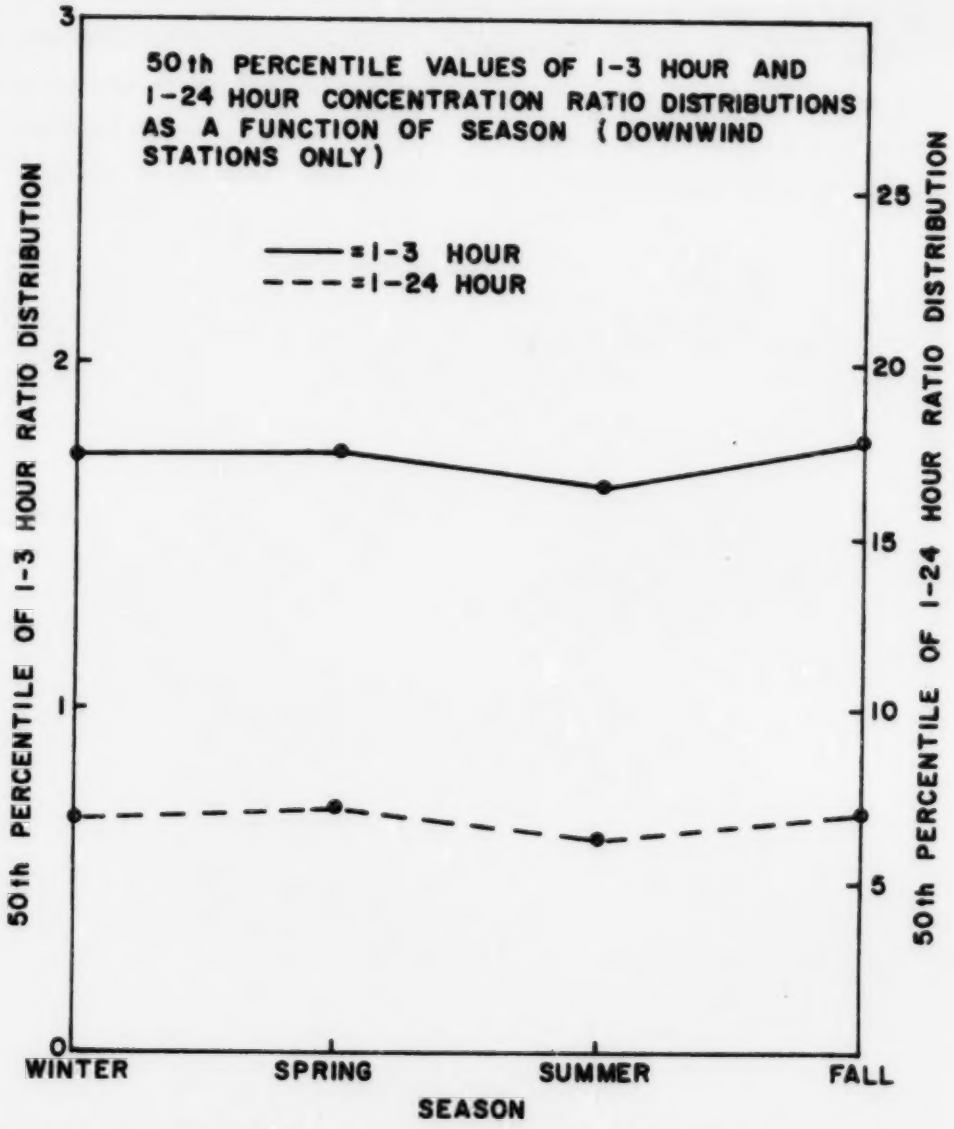

Figure 19. Fifty percentile values of 1 to 3 hour and 1 to 24 hour concentration ratio distributions as a function of season for downwind stations only

The resultant sensitivity plots show much the same behavior as the previous curves without the downwind restriction. One new feature is a rise in both 1 to 3 hour and 1 to 24 hour 50 percentile values for the highest windspeeds. The increase in 50 percentile values during midday is still evident but the peak appears to be much broader. The trend toward lower 50 percentile ratios at greater distances from the plant is still present. Again there is no obvious effect on the 50 percentile values from season to season. The correlation between the peak 1 hour concentration and the 1 to 3 hour ratio was found to be -0.018.

SECTION V

MODEL VALIDATION PROCEDURE

MODEL DESCRIPTION

The diffusion model used in this validation study was a gaussian type model developed by EPA Division of Meteorology. The code was written to calculate maximum daily concentrations of SO_2 for a year, meteorological conditions which can lead to these maxima, and hourly and daily concentrations for an array of receptor locations. These concentrations are written on tape for the 180 receptor positions situated at each of 36 directions from the source and five different distance ranges. The model can handle from 1 to 19 sources but treats all of them as if they were at the same physical location.

Meteorological input to the model consists of hourly surface observations of wind speed (knots), wind direction sector (1-36), temperature (^{o}F), total cloud cover (tenths), and twice daily mixing depths (meters). The format for these data is that used by the National Climatic Center for WBAN-144 hourly surface observations. These data are input into a preprocessor program which in turn writes a tape containing hourly values of stability index, mixing height, temperature, windspeed, flow vector (wind direction plus 180^{o}), and randomized flow vector. The randomized flow vector is equal to the flow vector minus 4 degrees plus a random number between 0 and 9 degrees. The preprocessor output tape is then read by the Single Source Model which performs the actual concentration calculations.

The preprocessor program generates hourly mixing depths from the twice daily mixing depth measurements according to the interpolation scheme for rural areas given in the Single Source Model in the Interim User's Guide.[7] Hourly stabilities are determined according to the

system given by Turner[1] employing Pasquill's classification scheme with the addition of a stability class 7 for which the assumption is made that the plume does not reach the ground. Wind speeds u_o measured at instrument height h_o (7 meters for weather stations) are adjusted by means of a stability dependent power law $(u = u_o(h/h_o)^p$ to correspond to values one would expect at the stack top h. Plume rise is calculated on an hourly basis using the method of Briggs.[8] If the plume rise calculation indicates that the plume axis will rise above the mixing layer then a zero concentration contribution is specified. If the plume rise is below the top of the mixing layer, the presence of the top of the layer is accounted for by the introduction of image plumes[1] to satisfy the zero flux conditions at ground level and at the top of the mixing layer.

Source input to the Single Source Model may possess varying degrees of temporal resolution. In the seasonal version of the model an annual average SO_2 source strength is specified along with monthly variation factors. In addition to the seasonal factors, the diurnal version of the model employs hourly emission variation factors for each month of the year. A modified version of the model used in part of our validation study allowed actual hourly source strengths to be utilized.

VALIDATION RESULTS

After the completion of model runs using the four different source – meteorological data base combinations, hourly concentrations for those model stations closest to the actual measurement locations were compared with observed concentrations. Although in the model calculations an exact match could be made for receptor distances from the source, the specification of the appropriate angular displacements presented somewhat of a problem. In the first three model runs it was decided to retain the practice of adding a random displacement to the flow vector since the wind direction data was given only to the nearest 10 degrees. Hourly concentration data was then obtained from the model output tape for those model receptor locations which fell within the same 10 degree sector as the actual station. For the last validation case, no random

wind flow vector displacement was introduced so that model concentrations represent either plume centerline values or concentrations at multiples of 10 degrees from the centerline. It was felt that this procedure might improve the agreement between measured and calculated distributions especially for the higher concentrations.

For each model run the hourly and daily SO_2 concentrations for the appropriate model receptors were written on a second file for later construction of hourly and daily concentration frequency distributions which could then be compared with the measured distributions. The 5 percentile, 1 percentile, second highest, and highest concentrations are presented for measured and calculated values for 1 hour and 24 hour concentrations in Tables 7 and 8, respectively. Although the calculated 5 and 1 percentile values for all four model runs fall considerably below the measured values, the situation for the second highest and highest concentrations is not quite so extreme. Nevertheless the calculated concentrations for these last two categories are still consistently below the corresponding measured values. This situation is also illustrated by Figures 20(a)-(d) and Figures 21(a)-(d) which present cumulative frequency distributions of observed and calculated 1 hour and 24 hour concentrations. Even after background subtraction the measured and calculated 1 hour and 24 hour distributions do not agree even for the highest concentrations.

In order to improve the agreement between model calculations and observations, we examined for each hour the concentration prediction for direction displacements of -30°, -20°, -10°, 0°, 10°, 20°, 30°, and compared these to the measured values. For each of the four stations, we determined average calculated hourly concentrations, the standard error normalized by the average measured concentration, and correlation coefficients for each of the direction displacements. In addition, each of these parameters were also calculated for the direction displacement corresponding the best agreement between calculated and measured concentrations on an hour by hour basis. The results of this

Table 7. 1-HOUR CONCENTRATION DISTRIBUTION STATISTICS FOR MEASUREMENTS AND DIFFERENT MODEL VALIDATION RUNS[a]

Data base	5% station number				1% station number				Second highest concentration station number				Highest concentration station number			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Measured concentration corrected for background	25	14	18	15	101	72	18	31	435	553	446	575	436	618	732	638
1964 nearest station met. data and 1971 FPC data	<1	<1	<1	<1	42	15	1	<1	376	321	218	352	412	334	328	509
1971 nearest station met. data and 1971 FPC data	<1	<1	<1	<1	39	5	1	<1	213	276	265	313	237	337	640	325
1971 nearest station met. data and 1971 plant summary emissions	<1	<1	<1	<1	45	5	5	<1	261	297	440	318	278	380	730	334
1971 plant met. and emissions data	<1	<1	<1	<1	6	<1	2	<1	253	174	446	427	283	179	509	479

[a]Percentile values given in terms of cumulative percent of concentrations greater than given values.

Table 8. 24-HOUR CONCENTRATION DISTRIBUTION STATISTICS FOR MEASUREMENTS AND DIFFERENT MODEL VALIDATION RUNS[a]

Data base	5% station number				1% station number				Second highest concentration station number				Highest concentration station number			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Measured concentration corrected for background	32	15	17	15	52	28	46	44	66	36	77	63	75	46	83	75
1964 nearest station met. data and 1971 FPC data	9	6	2	1	30	20	8	14	30	30	15	22	33	41	24	35
1971 nearest station met. data and 1971 FPC data	9	4	<1	3	16	14	7	12	19	18	12	17	20	19	26	36
1971 nearest station met. data and 1971 plant summary emissions	9	4	3	4	19	16	10	15	23	20	20	21	25	21	31	44
1971 plant met. and emissions data	4	<1	4	<1	14	6	18	2	16	9	33	4	29	11	39	16

[a]Percentile values given in terms of cumulative percent of concentrations greater than given values.

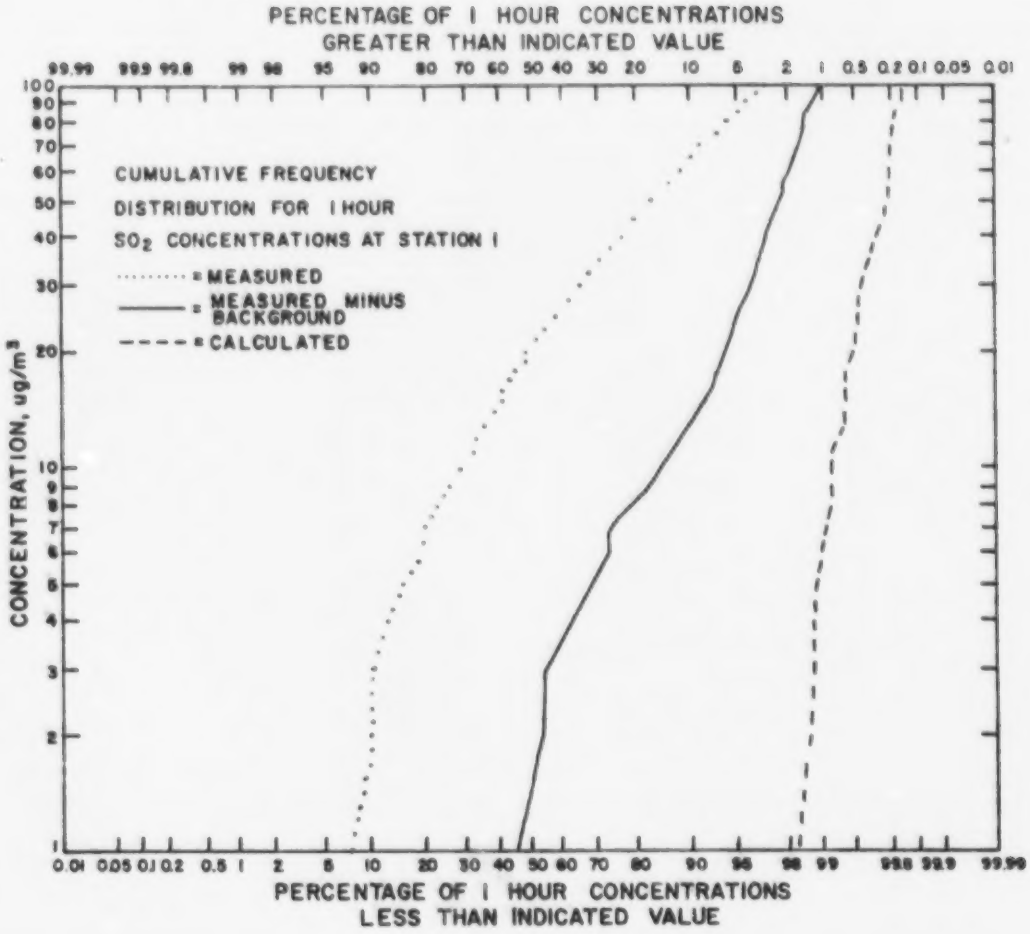
PERCENTAGE OF 1 HOUR CONCENTRATIONS
GREATER THAN INDICATED VALUE
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
CUMULATIVE FREQUENCY
DISTRIBUTION FOR 1 HOUR
SO2 CONCENTRATIONS AT STATION 1
..... = MEASURED
——— = MEASURED MINUS BACKGROUND
- - - - = CALCULATED
CONCENTRATION, ug/m3
100 90 80 70 60 50 40 30 20 10 9 8 7 6 5 4 3 2 1
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
PERCENTAGE OF 1 HOUR CONCENTRATIONS
LESS THAN INDICATED VALUE

Figure 20(a). Cumulative frequency distributions for 1 hour SO_2 concentrations at station 1

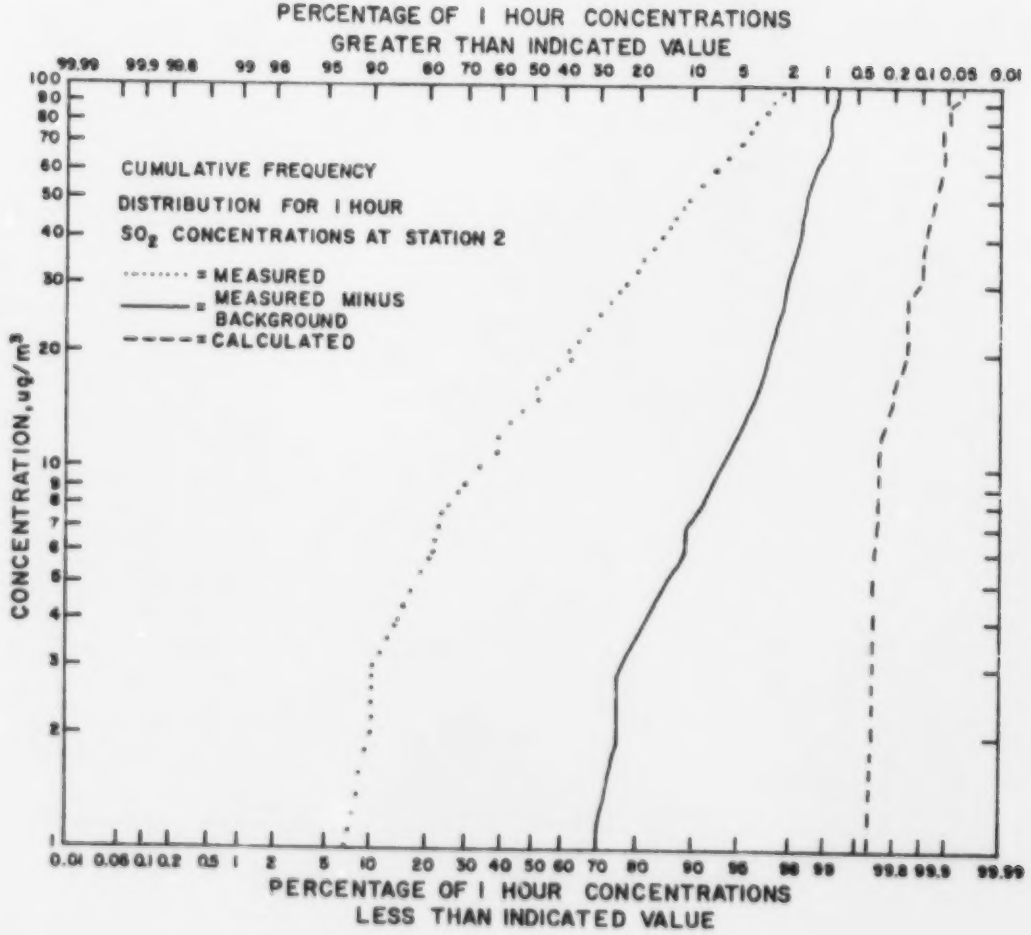
PERCENTAGE OF 1 HOUR CONCENTRATIONS
GREATER THAN INDICATED VALUE
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
CUMULATIVE FREQUENCY
DISTRIBUTION FOR 1 HOUR
SO2 CONCENTRATIONS AT STATION 2
..... = MEASURED
——— = MEASURED MINUS BACKGROUND
- - - - = CALCULATED
CONCENTRATION, µg/m³
100 90 80 70 60 50 40 30 20 10 9 8 7 6 5 4 3 2 1
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
PERCENTAGE OF 1 HOUR CONCENTRATIONS
LESS THAN INDICATED VALUE

Figure 20(b). Cumulative frequency distributions for 1 hour SO_2 concentrations at station 2

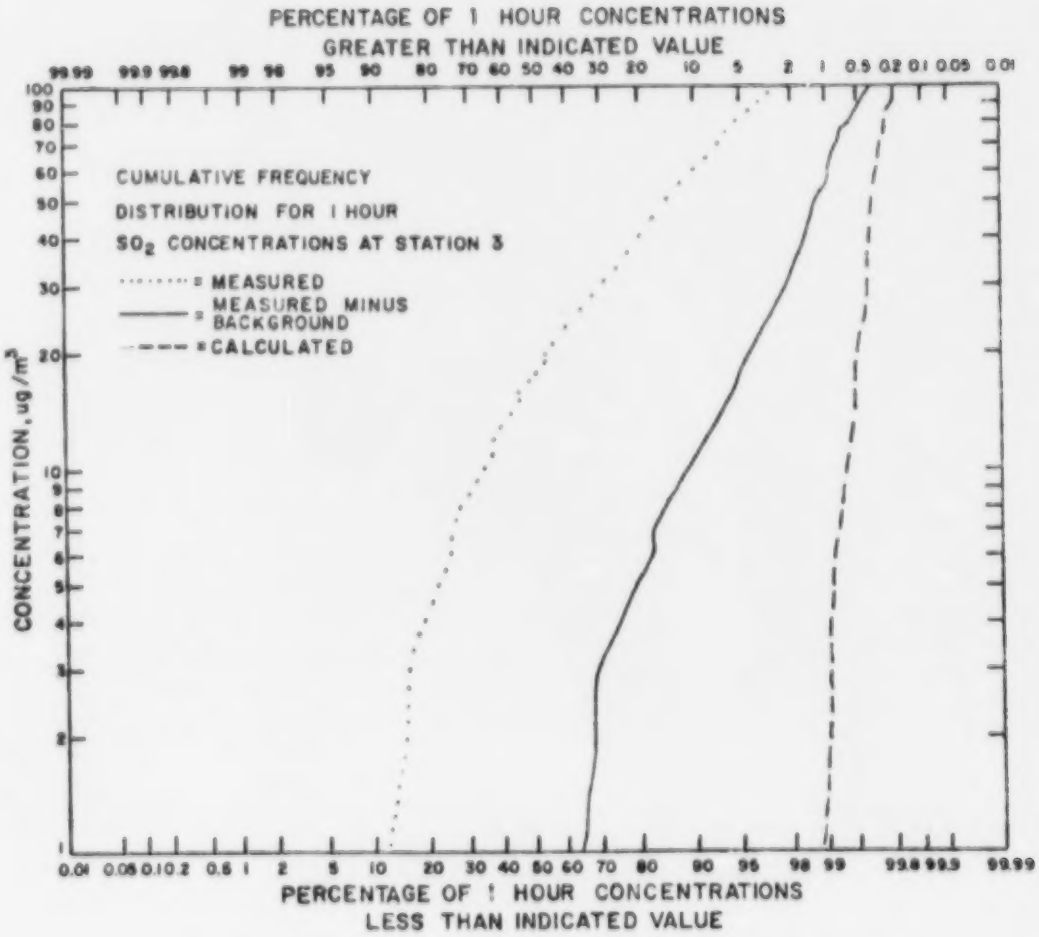
PERCENTAGE OF 1 HOUR CONCENTRATIONS
GREATER THAN INDICATED VALUE
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
CUMULATIVE FREQUENCY
DISTRIBUTION FOR 1 HOUR
SO2 CONCENTRATIONS AT STATION 3
= MEASURED
= MEASURED MINUS BACKGROUND
= CALCULATED
CONCENTRATION, ug/m3
100 90 80 70 60 50 40 30 20 10 9 8 7 6 5 4 3 2 1
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
PERCENTAGE OF 1 HOUR CONCENTRATIONS
LESS THAN INDICATED VALUE

Figure 20(c). Cumulative frequency distributions for 1 hour SO_2 concentrations at station 3

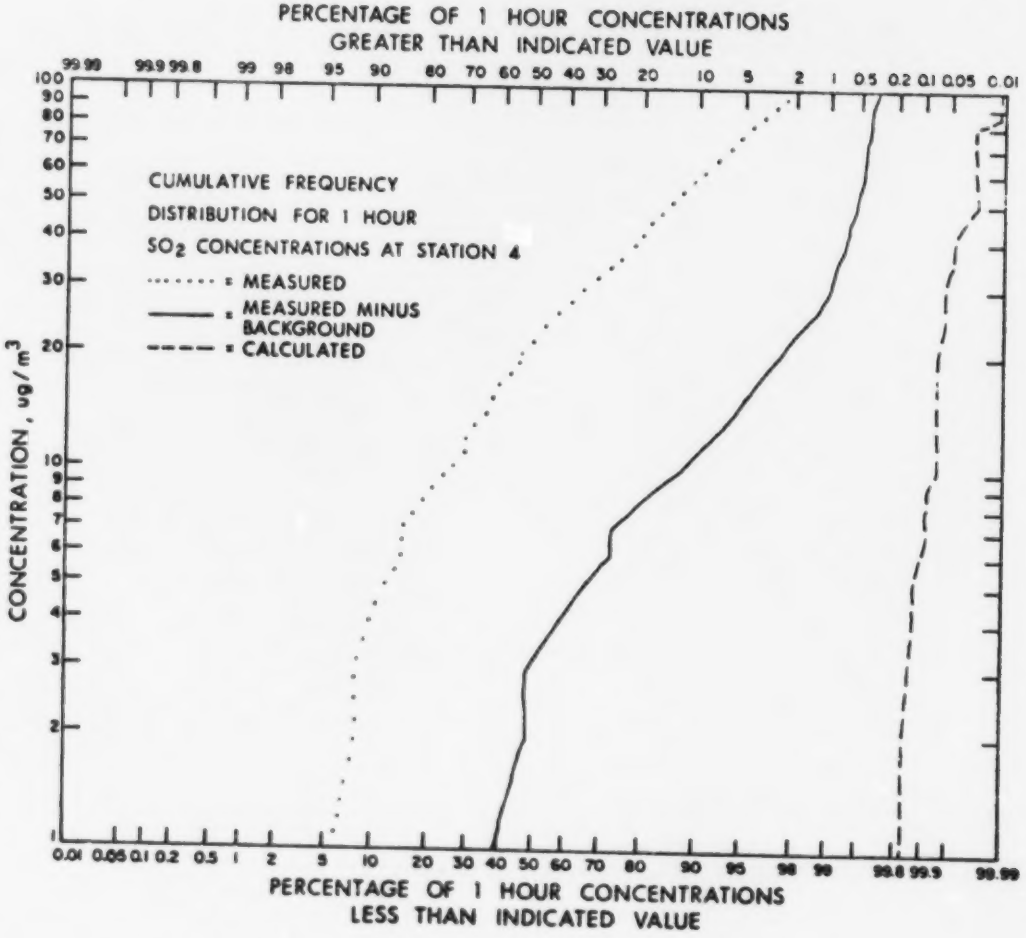
PERCENTAGE OF 1 HOUR CONCENTRATIONS
GREATER THAN INDICATED VALUE
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
CUMULATIVE FREQUENCY
DISTRIBUTION FOR 1 HOUR
SO2 CONCENTRATIONS AT STATION 4
..... = MEASURED
——— = MEASURED MINUS BACKGROUND
– – – – = CALCULATED
CONCENTRATION, ug/m3
100 90 80 70 60 50 40 30 20 10 9 8 7 6 5 4 3 2 1
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
PERCENTAGE OF 1 HOUR CONCENTRATIONS
LESS THAN INDICATED VALUE

Figure 20(d). Cumulative frequency distributions for 1 hour SO_2 concentrations at station 4

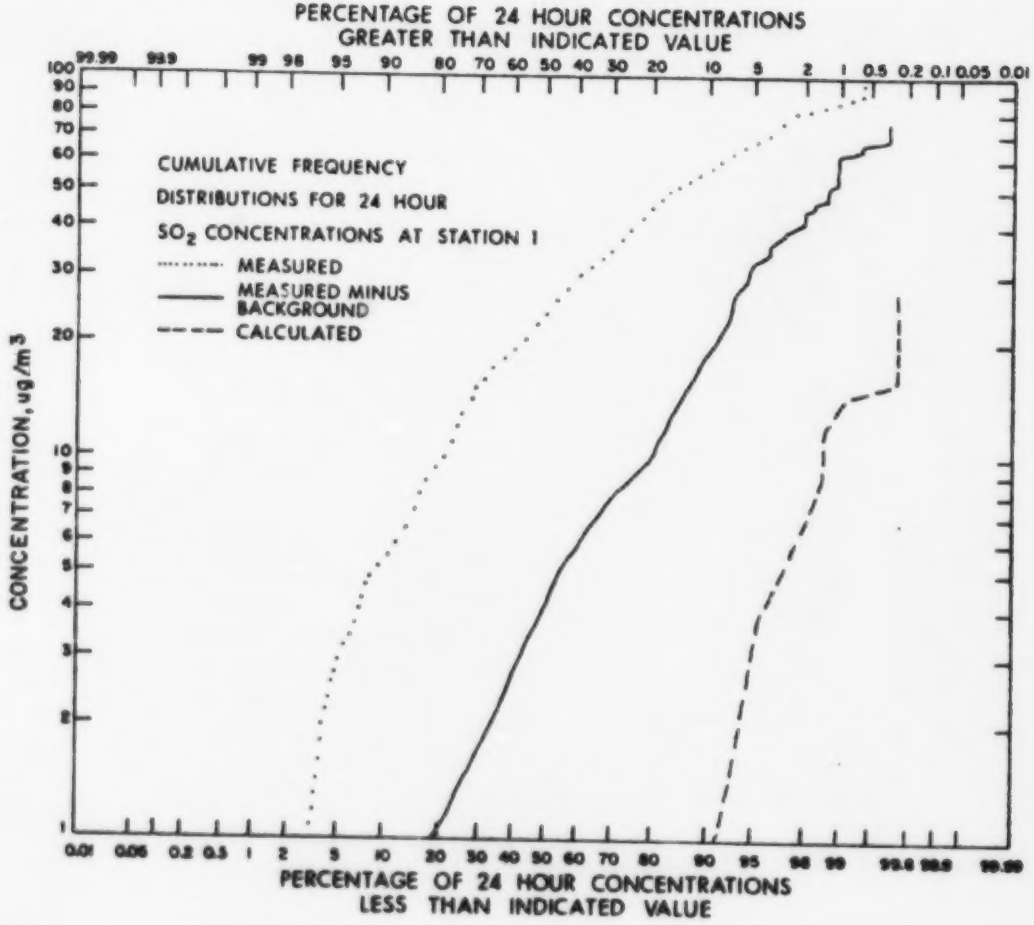
PERCENTAGE OF 24 HOUR CONCENTRATIONS
GREATER THAN INDICATED VALUE
99.99 99.9 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
CUMULATIVE FREQUENCY
DISTRIBUTIONS FOR 24 HOUR
SO2 CONCENTRATIONS AT STATION 1
MEASURED
MEASURED MINUS BACKGROUND
CALCULATED
CONCENTRATION, ug/m3
100 90 80 70 60 50 40 30 20 10 9 8 7 6 5 4 3 2 1
0.01 0.05 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
PERCENTAGE OF 24 HOUR CONCENTRATIONS
LESS THAN INDICATED VALUE

Figure 21(a). Cumulative frequency distributions for 24 hour SO_2 concentrations at station 1

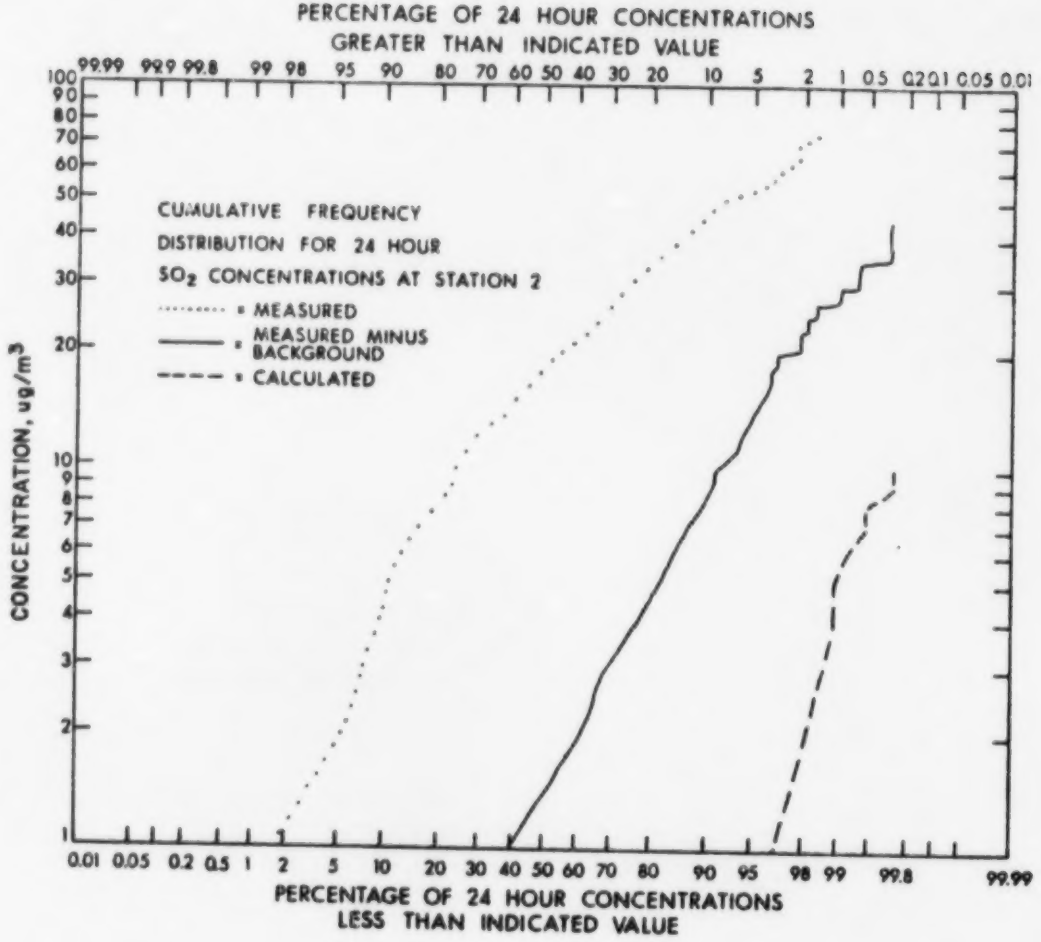
PERCENTAGE OF 24 HOUR CONCENTRATIONS
GREATER THAN INDICATED VALUE
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
CUMULATIVE FREQUENCY
DISTRIBUTION FOR 24 HOUR
SO_2 CONCENTRATIONS AT STATION 2
..... = MEASURED
——— = MEASURED MINUS BACKGROUND
– – – – = CALCULATED
CONCENTRATION, ug/m³
100 90 80 70 60 50 40 30 20 10 9 8 7 6 5 4 3 2 1
0.01 0.05 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.99
PERCENTAGE OF 24 HOUR CONCENTRATIONS
LESS THAN INDICATED VALUE

Figure 21(b). Cumulative frequency distribution for 24 hour SO_2 concentrations at station 2

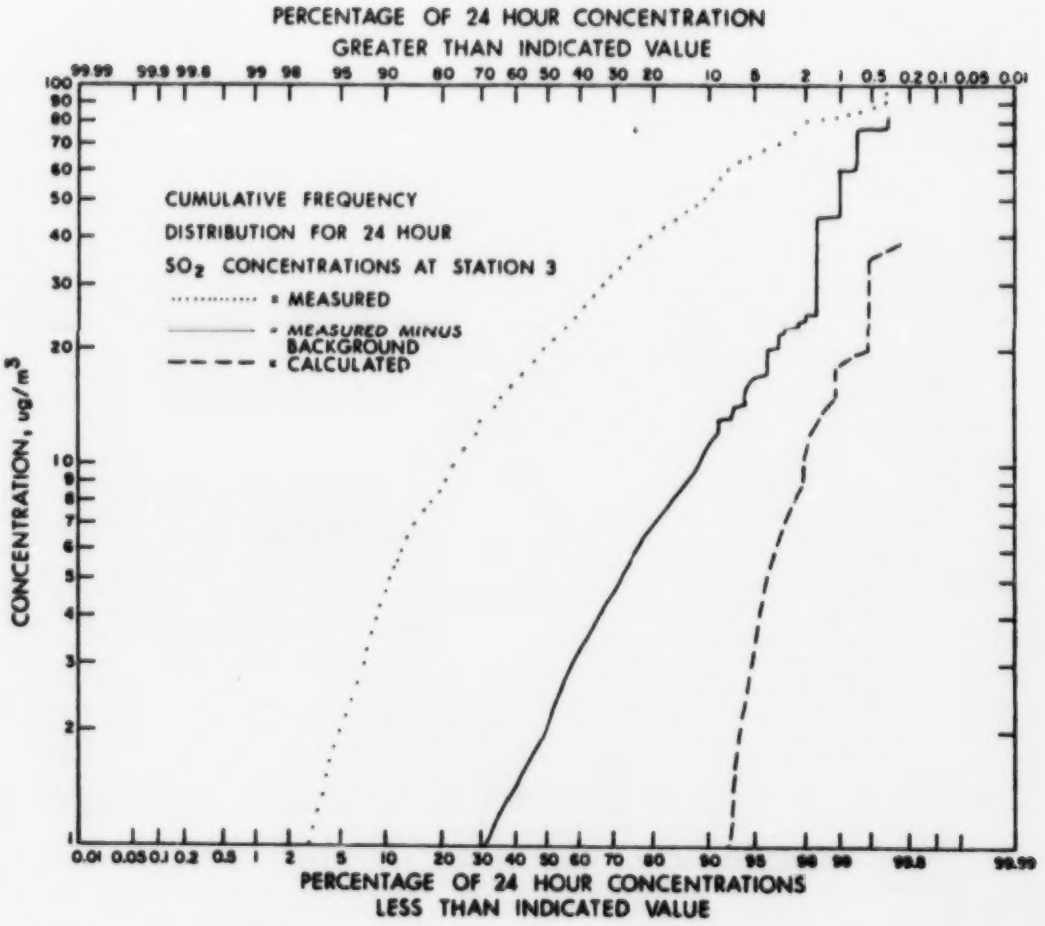
PERCENTAGE OF 24 HOUR CONCENTRATION
GREATER THAN INDICATED VALUE
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
CUMULATIVE FREQUENCY
DISTRIBUTION FOR 24 HOUR
SO2 CONCENTRATIONS AT STATION 3
..... = MEASURED
——— = MEASURED MINUS BACKGROUND
– – – = CALCULATED
CONCENTRATION, ug/m3
100 90 80 70 60 50 40 30 20 10 9 8 7 6 5 4 3 2 1
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.99
PERCENTAGE OF 24 HOUR CONCENTRATIONS
LESS THAN INDICATED VALUE

Figure 21(c). Cumulative frequency distribution for 24 hour SO_2 concentrations at station 3

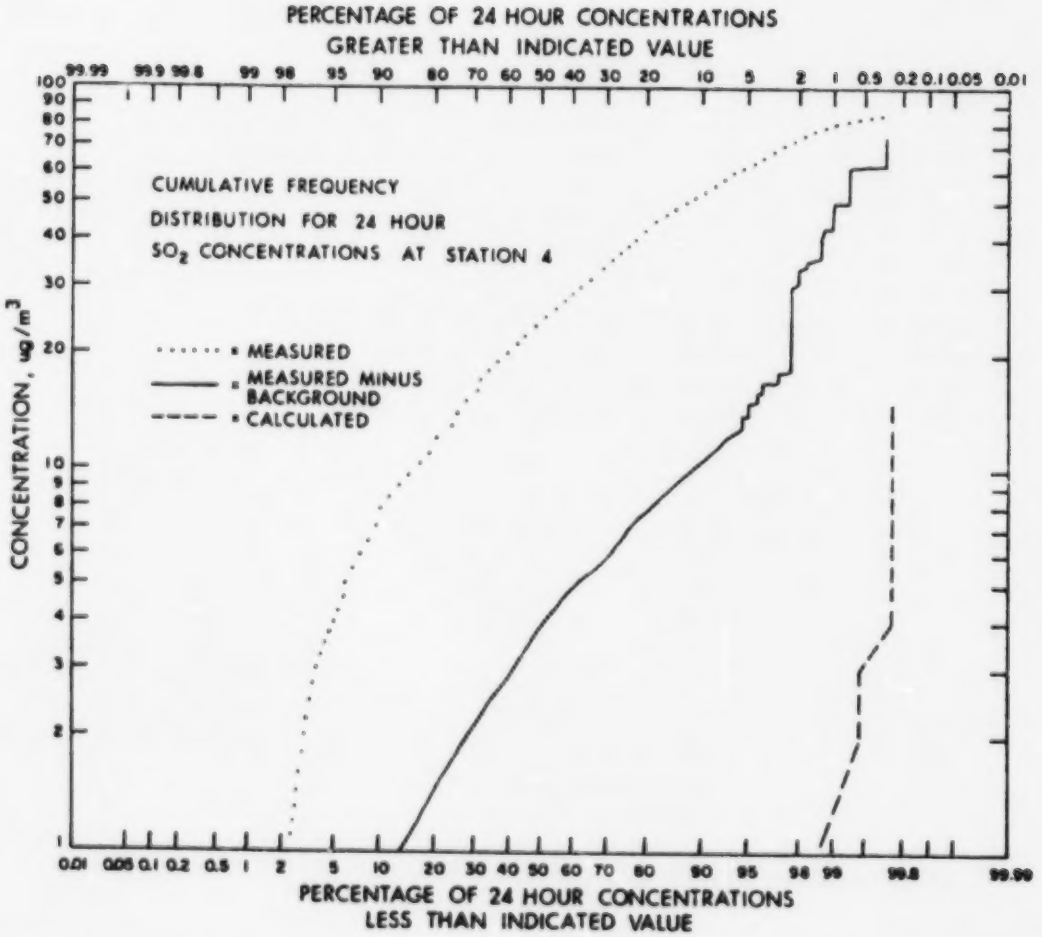
PERCENTAGE OF 24 HOUR CONCENTRATIONS
GREATER THAN INDICATED VALUE
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
CUMULATIVE FREQUENCY
DISTRIBUTION FOR 24 HOUR
SO_2 CONCENTRATIONS AT STATION 4
MEASURED
MEASURED MINUS BACKGROUND
CALCULATED
CONCENTRATION, $\mu g/m^3$
100 90 80 70 60 50 40 30 20 10 9 8 7 6 5 4 3 2 1
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.99
PERCENTAGE OF 24 HOUR CONCENTRATIONS
LESS THAN INDICATED VALUE

Figure 21(d). Cumulative frequency distribution for 24 hour SO_2 concentrations at station 4

Table 9. MODEL VALIDATION RESULTS FOR HOURLY CONCENTRATION

Station no.	Validation parameter	Direction displacement							
		-30°	-20°	-10°	0°	10°	20°	30°	Best
	Average measured hourly concentration								
1		-	-	-	7.0	-	-	-	-
2		-	-	-	3.6	-	-	-	-
3		-	-	-	4.4	-	-	-	-
4		-	-	-	5.0	-	-	-	-
	Average calculated hourly concentrations								
1		0.57	0.77	0.72	0.51	0.23	0.29	0.48	0.74
2		0.38	0.26	0.12	0.14	0.36	0.68	1.3	0.09
3		0.077	0.026	0.036	0.078	0.096	0.054	0.077	0.015
4		0.26	0.20	0.25	0.28	0.23	0.40	0.55	0.34
	Standard error normalized by average measured concentration								
1		3.36	3.36	3.17	3.17	3.26	2.42	3.45	2.89
2		5.29	5.10	5.01	5.01	5.38	5.66	6.59	4.82
3		4.28	4.19	4.19	4.19	4.28	4.28	4.28	4.19
4		3.87	3.87	3.78	4.05	3.96	4.05	4.32	3.33
	Correlation coefficients								
1		0.11	0.17	0.24	0.22	0.093	0.002	-0.006	0.50
2		0.037	0.051	0.036	0.005	-0.003	0.001	-0.001	0.11
3		-0.004	-0.006	-0.002	-0.002	-0.002	-0.002	-0.002	0.035
4		0.15	0.16	0.27	0.012	0.019	0.021	0.0	0.68

study are given in Table 9. The first point to be noticed from this calculation is the drastic improvement in the correlation coefficient which occurs if the predicted concentration for the "best" direction displacement is chosen for the calculated concentration. The standard error also decreases for the best displacement but the effect is not as significant as was the case for the correlation coefficient. Another interesting feature is the consistent improvement in the correlation coefficient for negative direction displacements.

The lack of agreement between measured and calculated concentrations may be traced to several factors. The most important reason for the disagreement may well be an overestimation of plume height by the model for the most commonly observed atmospheric stabilities and a consequent overriding of the monitoring stations by the plume. Under these conditions the model predicts that the maximum concentration will be found beyond any of the actual receptor locations. Table 10 contains the output of the EPA UNAMAP program PTMAX which finds the maximum concentrations and distance to the maxima for a range of stabilities and wind speeds. The actual stack height for this calculation was corrected for the difference in elevation between the stack base and the receptor locations. The PTMAX results show that no appreciable concentration can be expected for stability indices greater than 3. Even for stability 3 the wind speed must be greater than 5m/sec for the maximum to fall within the range of the station farthest from the source. Since a stability of 3 or below occurred only 17 percent of the time for the 1971 meteorological data, few opportunities are presented for calculated elevated concentrations within the area covered by the monitoring network.

Another difficulty arises from the fact that even when stability and wind conditions are favorable for the observations of high concentrations the calculated plume spread is not sufficiently large to affect more than one model receptor location. The use of this rather sharply

Table 10. ANALYSIS OF CONCENTRATION MAXIMA FOR DIFFERENT WIND SPEEDS AND STABILITIES WITH 1971 CANAL PLANT OPERATING CHARACTERISTICS

CANAL PLANT 1971

ANALYSIS OF CONCENTRATION AS A FUNCTION OF STABILITY AND WIND SPEED.
1971 VERSION, D. B. TURNER.

EMISSION RATE (G/SEC) = 843.71
PHYSICAL STACK HEIGHT (M) = 92.33
STACK GAS TEMP (DEG K) = 422.00
AMBIENT AIR TEMPERATURE (DEG K) = 294.
VOLUME FLOW (CU M/SEC) = 468.73

STABILITY	WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HEIGHT (M)
1	0.5	9.90000+01	999.000(1)	3361.9(2)
1	0.8	9.90000+01	999.000(1)	2120.3(2)
1	1.0	2.752[illegible]-04	1.724	1717.1(2)
1	1.5	3.139[illegible]-04	1.441	1160.9(2)
1	2.0	3.436[illegible]-04	1.269	894.7(2)
1	2.5	3.666[illegible]-04	1.153	730.2(2)
1	3.0	3.847[illegible]-04	1.069	620.6(2)
2	0.5	9.90000+01	999.000(1)	3361.9(2)
2	0.8	9.90000+01	999.000(1)	2120.3(2)
2	1.0	7.69744-05	9.444	1717.1(2)
2	1.5	1.02297-04	6.665	1167.9(2)
2	2.0	1.26065-04	5.210	894.7(2)
2	2.5	1.43075-04	4.321	730.2(2)
2	3.0	1.59868-04	3.722	620.6(2)
2	4.0	1.87970-04	2.984	483.5(2)
2	5.0	2.10571-04	2.498	401.3(2)
3	2.0	7.65620-05	12.991	894.7(2)
3	2.5	9.14259-05	10.399	730.2(2)
3	3.0	1.05815-04	8.897	620.6(2)
3	4.0	1.28978-04	6.818	483.5(2)
3	5.0	1.48198-04	5.393	401.3(2)
3	7.0	1.80778-04	4.022	287.3(2)
3	10.0	2.12254-04	3.021	236.9(2)
3	12.0	2.25906-04	2.639	209.4(2)
3	15.0	2.38766-04	2.263	182.0
4	0.5	9.90001+01	999.000(1)	3361.9(2)
4	0.8	9.90000+01	999.000(1)	2120.3(2)
4	1.0	9.90000+01	999.000(1)	1717.1(2)
4	1.5	8.00000-06	234.926(3)	1160.9(2)
4	2.0	1.21445-05	137.414(3)	894.7(2)
4	2.5	1.67146-05	92.521	730.2(2)
4	3.0	2.15408-05	67.027	620.6(2)
4	4.0	3.16361-05	41.269	483.5(2)
4	5.0	4.18158-05	30.128	401.3(2)
4	7.0	5.98479-05	19.657	287.3(2)
4	10.0	8.03195-05	12.041	236.9(2)
4	12.0	9.15916-05	9.809	209.4(2)
4	15.0	1.04268-04	7.791	182.0
4	20.0	1.17746-04	5.981	154.6
5	2.0	1.54508-04	31.248	249.7(2)
5	2.5	1.68163-04	27.820	231.4(2)
5	3.0	1.62515-04	25.359	222.0(2)
5	4.0	1.33546-04	21.984	204.3(2)
5	5.0	1.25707-04	19.812	198.0
6	2.0	9.90000+01	999.000(1)	216.5(2)
6	2.5	9.90000+01	999.000(1)	204.3(2)
6	3.0	5.09918-05	91.550	198.0
6	4.0	6.97567-05	70.290	195.2
6	5.0	6.68012-05	62.811	177.1

(1) THE DISTANCE TO THE POINT OF MAXIMUM CONCENTRATION IS SO GREAT THAT THE BASIC STABILITY IS NOT LIKELY TO PERSIST LONG ENOUGH FOR THE PLUME TO TRAVEL THIS FAR.

(2) THE PLUME AT THIS STABILITY HEIGHT MUST EXTREME CAUTION SHOULD BE USED IN INTERPRETING THIS COMPUTATION AS THIS STABILITY TYPE MAY NOT EXIST AT THIS HEIGHT. ALSO WIND SPEED VARIATIONS WITH HEIGHT MAY CREATE A DIFFERENT SITUATION.

(3) NO COMPUTATION WAS ATTEMPTED FOR THIS CONDITION AS THE POINT OF MAXIMUM CONCENTRATION IS GREATER THAN 100 KILOMETERS FROM THE SOURCE.

peaked lateral concentration distribution effectively excludes a large number of low and medium size concentrations which would have otherwise been predicted. This point will be discussed in much greater detail in Section VII.

SECTION VI

COMPARISON WITH OTHER WORK

CONCENTRATION RATIO DISTRIBUTIONS

Most studies of concentration ratio distributions have involved peak values averaged over periods of only a few minutes. One such evaluation of SO_2 concentration ratio distributions was carried out by the Tennessee Valley Authority (TVA)[2] in the vicinity of the Paradise Power Plant with data taken over a 2-1/2 year period from January 1968 through June 1970. During this time period, 14 SO_2 monitors located in the 22-1/2 degree prevailing downwind sector were operated on a continuous basis. All but one of the stations were located within a distance of from 3 to 10 km from the plant. From the concentration data peak-to-1-hour average and peak-to-24-hour average concentration ratios were obtained for each measuring instrument. The highest 5-minute average concentration that occurred during a particular hour was considered to be the peak concentration for that hour. To avoid interference from background contributions, those hours with average concentrations less than 0.10 ppm were excluded from the analysis. The resulting ratio distributions were analyzed according to stability type and receptor distance from the source. Stability assignments (unstable neutral, stable) were made according to the potential temperature gradient which was obtained from hourly temperature measurements at 13m and 110m meteorological tower levels.

Although the procedure for background subtraction and determination of peak concentrations was different from those used in our study, their results correlate quite well with our findings. In particular, they

found a general decrease in concentration ratios for increasing stability and increasing distance from the source.

Although the ratio distributions obtained from the Paradise and Canal studies cannot be exactly compared due to different averaging times, a rough comparison, shown in Table 11, can be made if the Paradise values are corrected for averaging time by the method outlined in Table 5.1 of Turner's[1] Workbook. While the agreement between the 1 to 3 hour ratios appears to be quite good, the Paradise 1 to 24 hour ratios are about a factor of 2 greater than those for Canal.

Table 11. COMPARISON OF PARADISE CONCENTRATION RATIOS (CORRECTED FOR SAMPLING TIME) WITH DOWNWIND RATIOS OBTAINED AT CANAL

	Mean 1-3 hour	Mean 1-24 hour	50% 1-3 hour	50% 1-24 hour	95% 1-3 hour	95% 1-24 hour
Canal	1.90	8.54	1.66	6.75	1.10	2.15
Paradise	1.80	15.9	1.63	12.4	0.99	4.00

MODEL VALIDATION

Concentration data from the same TVA Paradise Steam Plant was also used by Klug[3] in a model validation study similar to our Canal Plant work. The Paradise Plant has three units, the first two of which are rated at 704 MW and the third has a capacity of 1150 MW. The corresponding stack heights associated with each unit are 183m, 183m and 244m.

In addition to hourly SO_2 concentration data for 6 stations in the prevailing downwind direction from the plant, SO_2 emissions, source operating characteristics and meteorological data were available on an hourly basis. Windspeed and direction measurements were made at a height of 110m above the ground. Atmospheric stabilities were calculated for each hour based upon the temperature difference between the 110m and 1m levels and wind speed observations at 13m. Although the effect of

SO_2 background was accounted for in the concentration ratio study described in Part A, no correction was made for background in the model validation exercise.

Model calculations were carried out using both the dispersion curves given by Turner[1] as well as the more recent curves obtained from Smith's[10] K-Theory computations. Once the receptor concentration was calculated for a measured wind direction at 110m height, the wind vector was arbitrarily shifted by increments of $\pm 10^{\circ}$, $\pm 20^{\circ}$, and $\pm 30^{\circ}$ to investigate the effects of plume centerline shift due to windshear. The results by this model validation study along with the corresponding findings of the Canal Plant modeling effort are given below.

1. Mean Value

   (a) Paradise Validation - The ratio of observed to calculated mean annual values for the 6 receptor locations ranged from 0.55 to 1.94 for the Turner σ_z values and 0.44 to 1.31 for the Smith σ_z values.

   (b) Canal Validation - Ratios of observed to calculated annual concentrations for the 4 receptor locations ranged from 13.7 to 56.4 for the Turner σ_z values.

2. Standard Error of Estimate

   (a) Paradise Validation - The standard error of estimate between observed and calculated concentrations is approximately 3 to 4 times the mean measured values.

   (b) Canal Validation - The standard error for the 4 stations ranged from 3.2 to 4.0.

3. Correlation Coefficients

   (a) Paradise Validation - The correlation coefficient between the logarithm of concentations varies

between 0.18 and 0.28. By arbitrarily shifting the wind vector to find the "best" predicted concentration the correlation coefficient is found to vary between 0.47 and 0.65.

(b) Canal Validation - The correlation coefficient between measured and calculated concentrations (not logarithms of concentrations) was in the range of 0.01 to 0.22. If the "best" direction displacement was chosen the range was 0.035 to 0.68. The correlation between the logarithms of concentrations were not calculated due large number of zero concentrations predicted by the model.

4. Effect of Wind Shear upon Concentration.

(a) Paradise Validation - The wind direction displacement which, on the average, gave the best agreement with measured concentration corresponded to a wind direction shift of + 20^{o}.

(b) Canal Validation - The best wind direction displacement represented a shift of between -10^{o} and -20^{o}.

One reason for the disagreement between the two validation studies for ratios of average measured and calculated concentrations was due to the fact that the Paradise stations were located within a 45^{o} sector from the stack. This would decrease the likelihood of an elevated concentration being observed at a particular station without its having been influenced in some way by the plume. In the case of the Canal Plant, the nature of the background subtraction process will result in non zero concentrations for stations upwind from the plume. There still remains the difficulty that the model is under predicting even

for the highest concentrations, a situation which may result in a large part from the choice of stability assignment and dispersion curves, or from an overestimation of plume height.

SECTION VII

SUGGESTIONS FOR MODEL IMPROVEMENT

In the course of our model validation activities we have found it necessary to make several changes in the Single Source Model. These changes were carried out to achieve a greater degree of flexibility in the input emissions and meteorological data. These minor modifications have included the following:

1. Input of actual SO_2 hourly emissions data.
2. Provision for a variable wind instrument height.
3. Elimination of the random angular displacement for the last validation run.
4. Specification of different elevations for each receptor distance from the source.

In addition to these minor improvements we have also noted the need for more substantial changes within the basic structure of the model itself. Based upon the model validation results presented in Section V, we offer the following two suggestions for model modifications which might lead to improved estimates within the Canal Plant network.

MODIFIED TREATMENT OF LATERAL PLUME SPREAD

As pointed out in Section V, the narrowness of the model plume appears to be responsible for many of the calculated zero concentrations at times when significant concentrations are observed. Some techniques for increasing the σ_y values (at short travel distances now based largely on 10-minute average values) or of averaging plume concentrations over an angular sector whose magnitude depends upon an estimate of wind direction variation during a given hour, might lead to better agreement

between measured and calculated frequency distributions for all but the highest concentration valves. The introduction of a random displacement does not appear to successfully alleviate the problem.

MODIFIED TECHNIQUES FOR THE PREDICTION OF PLUME RISE AND VERTICAL DISPERSION COEFFICIENTS

The fact that calculated concentrations fall consistently below measured values indicates that either the degree of plume rise has been overestimated or that the stability assignments are in need of revision. The plume rise formulation[8] used in the Single Source Model is based upon many sets of observations with each set weighted according to the amount and quality of the data. There is no guarantee that these formulas will be accurate when applied to a new site such as a seacoast facility. More observations of plume rise for different locations would be useful in the development of more refined prediction methods.

One such plume rise correction has recently been suggested by Briggs[9] and involves a plume rise retardation due to the presence of nearby structures. This consideration can be of considerable importance at the Canal Plant due to the fact that the stack site upon a building 59 meters in height.

The first correction in stack height is due to the stack aerodynamic effect.

$$h' = h_s + 2\ (v_s/u - 1.5)D \qquad (1)$$

where: h_s = actual stack height
v_s = stack gas exit velocity
u = wind speed
D = stack diameter

The next stack height correction will depend upon building height (h_b) and is given by one of the following three expressions:

Case 1.

$$h'' = h' \quad \text{if } h > 2.5\ h_b$$

Case 2.

$$h'' = 0 \quad \text{if } h' \leq 1.5\ h_b$$

Case 3.

$$h'' = 2h' - 2.5\ h_b \quad \text{if } 1.5\ h_b < h' \leq 2.5\ h_b$$

The standard plume rise correction due to buoyancy effects[8] is then applied to cases 1 and 3. For case 2 no buoyancy term is added, but an initial dilution volume of cross-sectional area h_b^2 is assumed.

After incorporation of these plume rise retardation corrections the Single Source Model was run once again with the random number option again utilized to locate the plume centerline within a 10 degree sector.

As shown in Figures 22 (a)-(d) and Figures 23 (a)-(d) the model distributions obtained using the plume rise correction are somewhat closer to the observations but indicate that the model is still under predicting to a considerable degree. The correlation coefficients given in Table 12 show only negligible improvement with respect to the previous validation run.

The discrepancy between model predictions and measured values is also illustrated in Table 13 which gives an hourly comparison between observed and calculated concentrations for observations over 200 $\mu g/m^3$. Many high observed concentrations are actually associated with zero

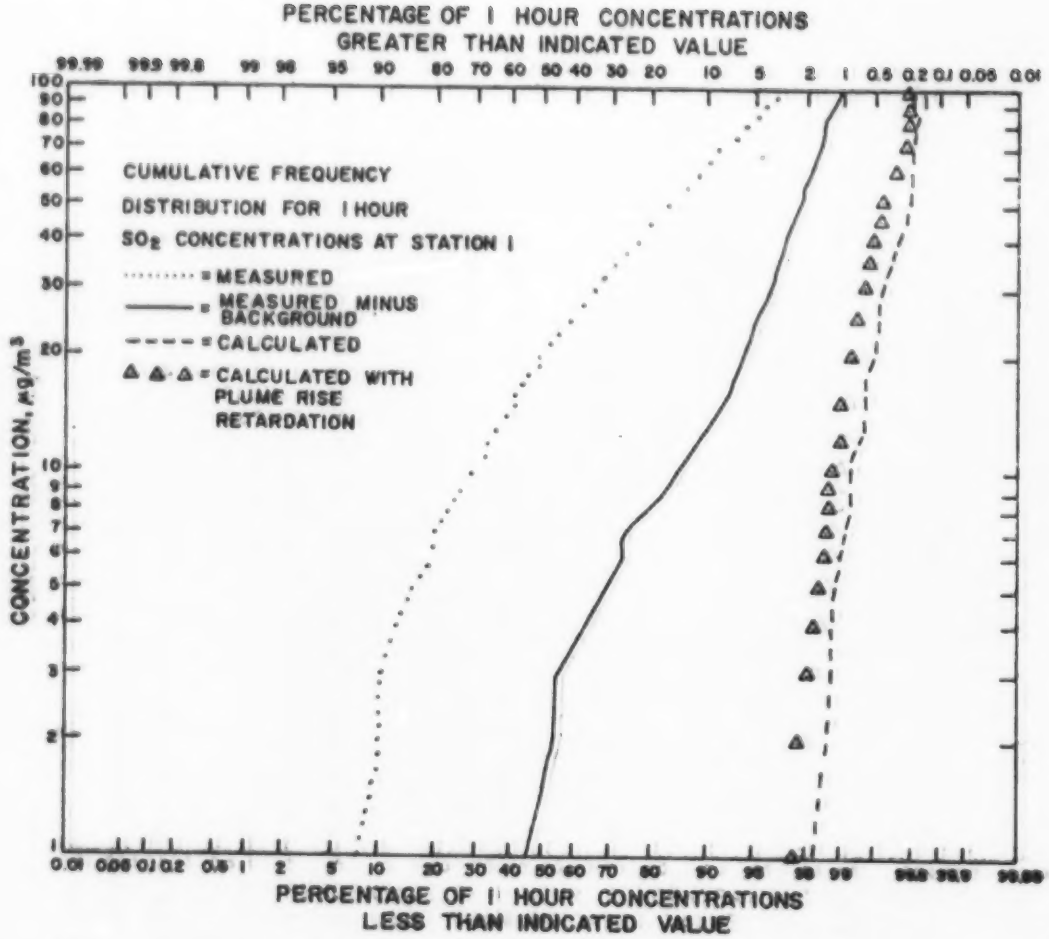
PERCENTAGE OF 1 HOUR CONCENTRATIONS
GREATER THAN INDICATED VALUE
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
CUMULATIVE FREQUENCY
DISTRIBUTION FOR 1 HOUR
SO2 CONCENTRATIONS AT STATION 1
..... = MEASURED
——— = MEASURED MINUS BACKGROUND
- - - - = CALCULATED
Δ Δ Δ = CALCULATED WITH PLUME RISE RETARDATION
CONCENTRATION, μg/m³
100 90 80 70 60 50 40 30 20 10 9 8 7 6 5 4 3 2 1
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.9 99.99
PERCENTAGE OF 1 HOUR CONCENTRATIONS
LESS THAN INDICATED VALUE

Figure 22(a). Cumulative frequency distribution for 1 hour SO_2 concentrations at station 1 (plume rise retardation included)

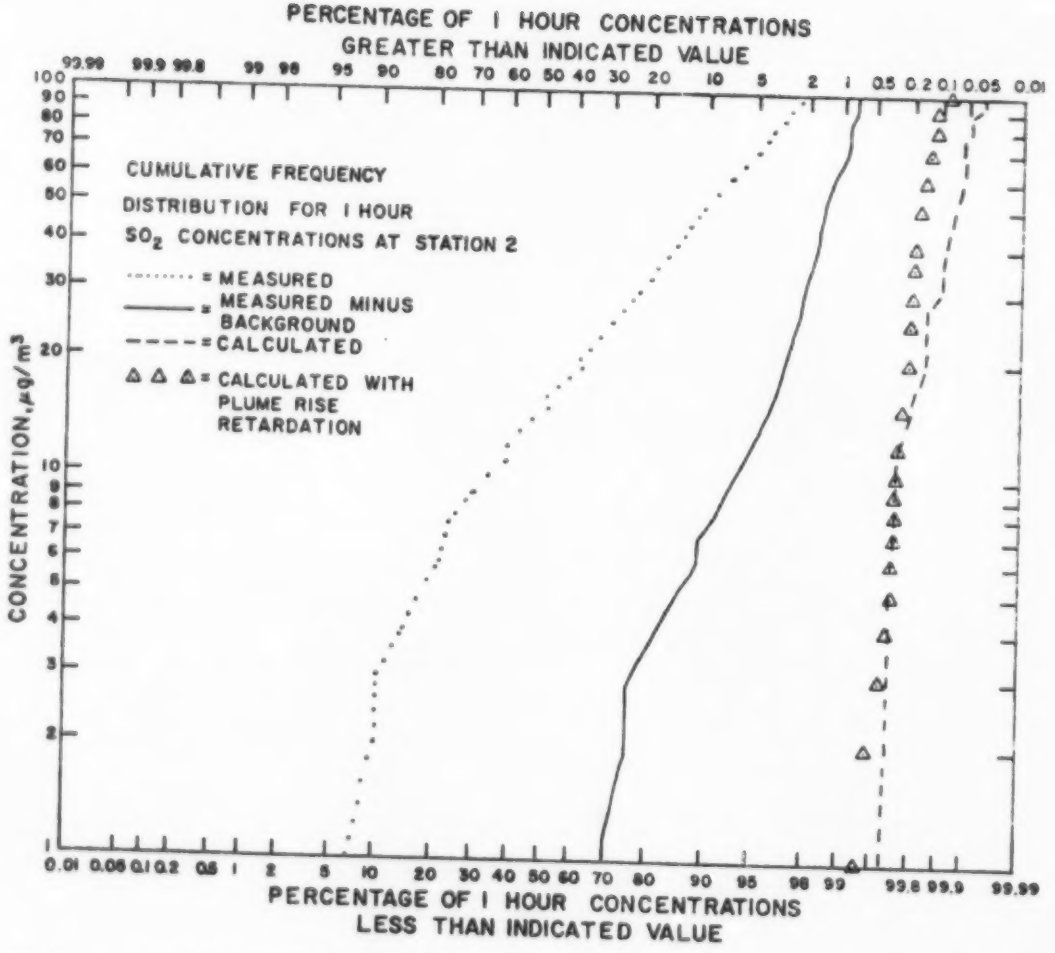
PERCENTAGE OF 1 HOUR CONCENTRATIONS
GREATER THAN INDICATED VALUE
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
CUMULATIVE FREQUENCY
DISTRIBUTION FOR 1 HOUR
SO_2 CONCENTRATIONS AT STATION 2
..... = MEASURED
——— = MEASURED MINUS BACKGROUND
– – – – = CALCULATED
Δ Δ Δ = CALCULATED WITH PLUME RISE RETARDATION
CONCENTRATION, μg/m³
100 90 80 70 60 50 40 30 20 10 9 8 7 6 5 4 3 2 1
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
PERCENTAGE OF 1 HOUR CONCENTRATIONS
LESS THAN INDICATED VALUE

Figure 22(b). Cumulative frequency distributions for 1 hour SO_2 concentrations at station 2 (plume retardation included)

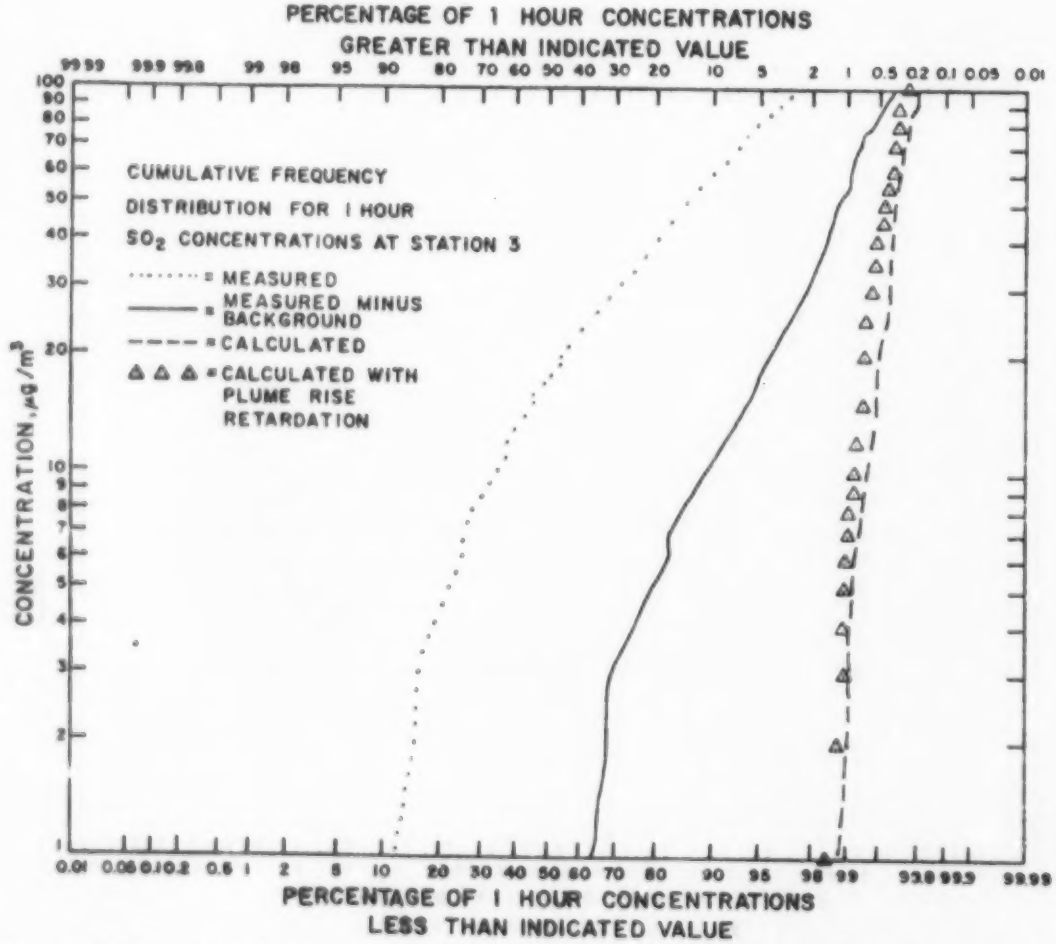
PERCENTAGE OF 1 HOUR CONCENTRATIONS
GREATER THAN INDICATED VALUE
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
CUMULATIVE FREQUENCY
DISTRIBUTION FOR 1 HOUR
SO_2 CONCENTRATIONS AT STATION 3
..... = MEASURED
——— = MEASURED MINUS BACKGROUND
– – – – = CALCULATED
Δ Δ Δ = CALCULATED WITH PLUME RISE RETARDATION
CONCENTRATION, μg/m³
100 90 80 70 60 50 40 30 20 10 9 8 7 6 5 4 3 2 1
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
PERCENTAGE OF 1 HOUR CONCENTRATIONS
LESS THAN INDICATED VALUE

Figure 22(c). Cumulative frequency distributions for 1 hour SO_2 concentrations at station 3 (plume rise retardation included)

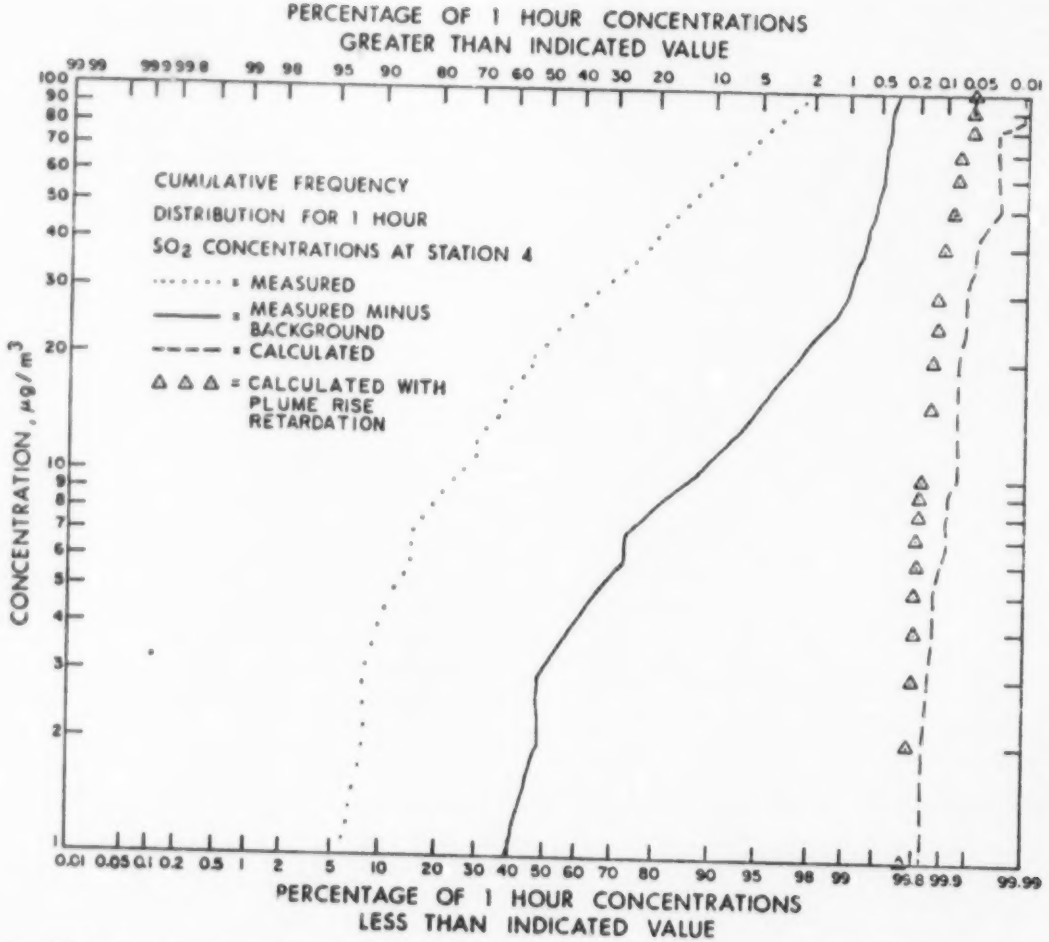
PERCENTAGE OF 1 HOUR CONCENTRATIONS
GREATER THAN INDICATED VALUE
CUMULATIVE FREQUENCY
DISTRIBUTION FOR 1 HOUR
SO2 CONCENTRATIONS AT STATION 4
..... = MEASURED
——— = MEASURED MINUS BACKGROUND
– – – – = CALCULATED
Δ Δ Δ = CALCULATED WITH PLUME RISE RETARDATION
CONCENTRATION, μg/m3
PERCENTAGE OF 1 HOUR CONCENTRATIONS
LESS THAN INDICATED VALUE

Figure 22(d). Cumulative frequency distributions for 24 hour SO_2 concentrations at station 4 (plume rise retardation included)

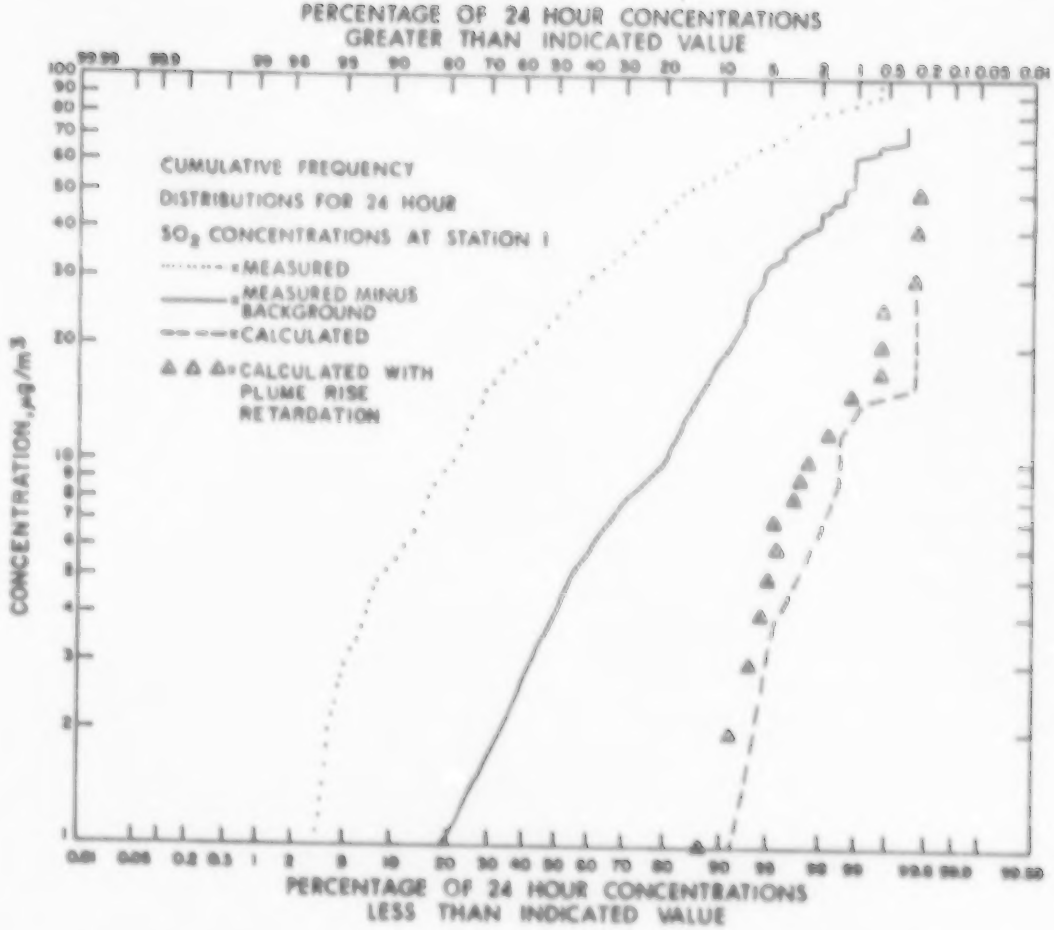

Figure 23(a). Cumulative frequency distributions for 24 hour SO_2 concentrations at station 1 (plume rise retardation included)

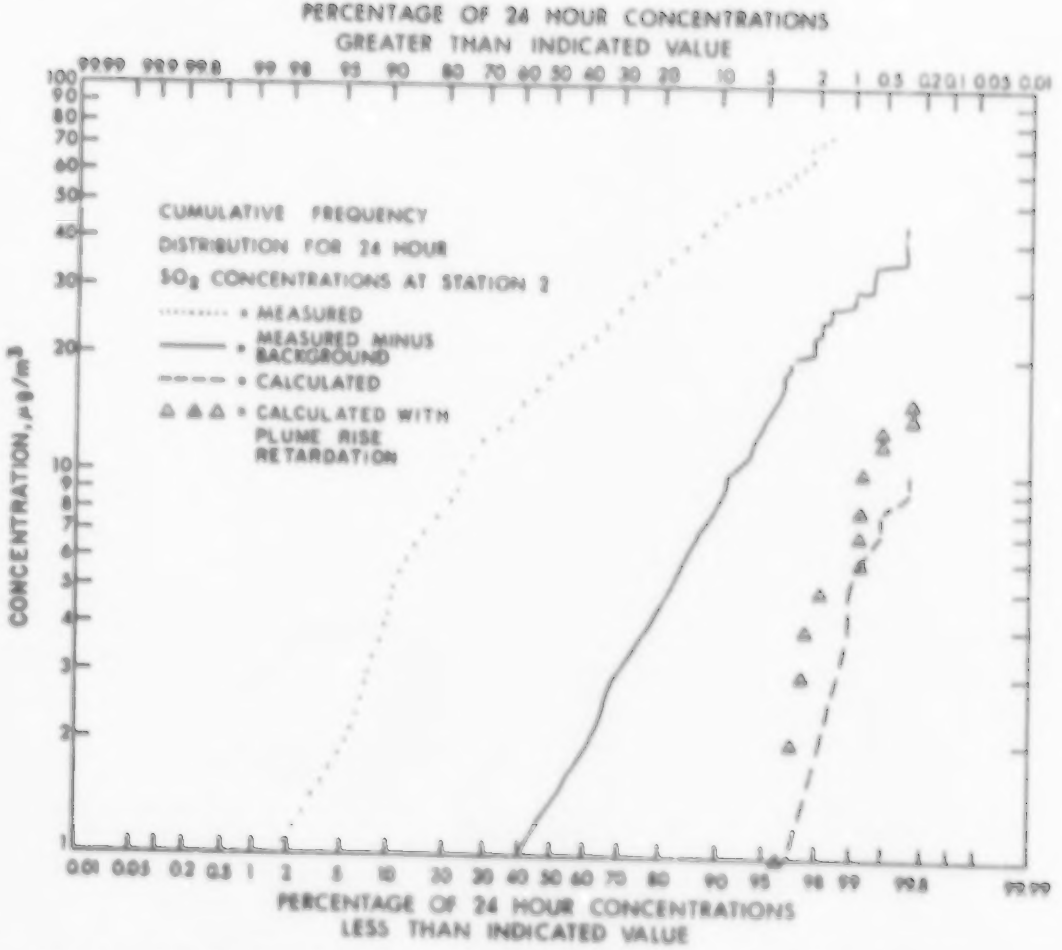

Figure 23(b). Cumulative frequency distributions for 24 hour SO_2 concentrations at station 7 (plume rise retardation included)

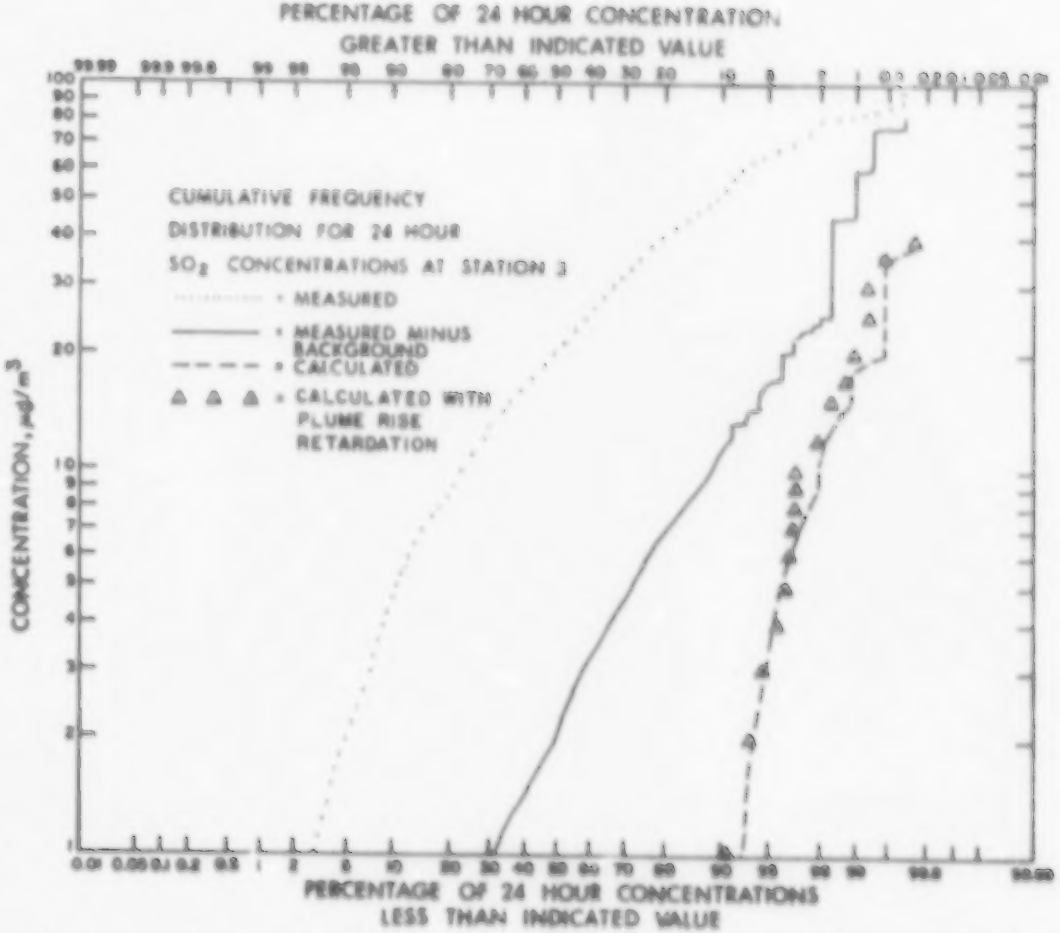
PERCENTAGE OF 24 HOUR CONCENTRATION GREATER THAN INDICATED VALUE
CUMULATIVE FREQUENCY
DISTRIBUTION FOR 24 HOUR
SO_2 CONCENTRATIONS AT STATION 3
MEASURED
MEASURED MINUS BACKGROUND
CALCULATED
CALCULATED WITH PLUME RISE RETARDATION
CONCENTRATION, $\mu g/m^3$
PERCENTAGE OF 24 HOUR CONCENTRATIONS LESS THAN INDICATED VALUE

Figure 23(c). Cumulative frequency distributions for 24 hour SO_2 concentrations at station 3 (plume rise retardation included)

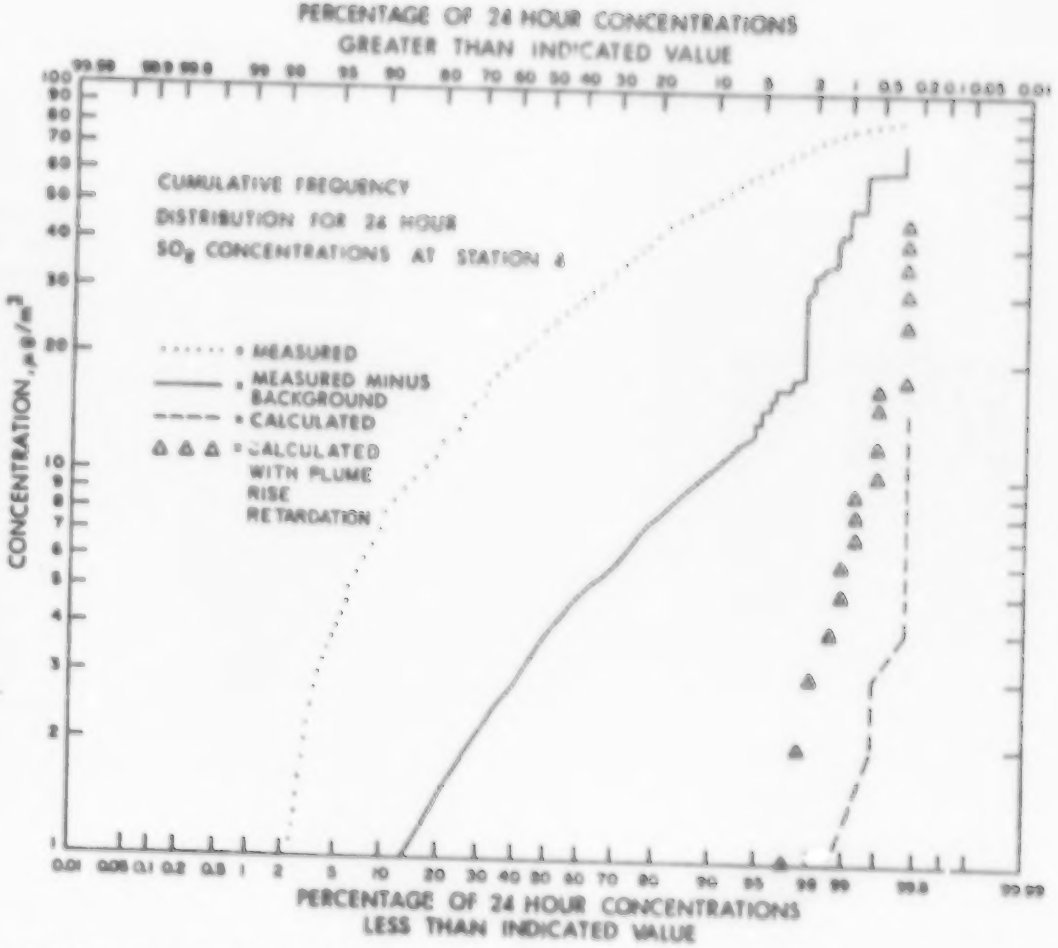

Figure 23(d). Cumulative frequency distribution for 24 hour SO_2 concentrations at station 4 (plume rise retardation included)

Table 12. MODEL VALIDATION RESULTS FOR HOURLY CONCENTRATION (WITH PLUME RISE CORRECTION)

Station no.	Validation parameter	Direction displacement							
		-30°	-20°	-10°	0°	10°	20°	30°	Best
	Average measured hourly concentration								
1		–	–	–	7.0	–	–	–	–
2		–	–	–	3.6	–	–	–	–
3		–	–	–	4.4	–	–	–	–
4		–	–	–	5.0	–	–	–	–
	Average calculated hourly concentrations								
1		0.84	1.3	1.4	0.84	0.36	0.43	0.81	1.1
2		1.7	0.60	0.18	0.22	0.63	1.80	3.60	0.094
3		0.69	0.16	0.10	0.28	0.56	0.69	0.74	0.022
4		0.43	0.37	0.51	0.64	0.72	0.93	1.10	0.58
	Standard error normalized by average measured concentration								
1		3.36	3.82	4.38	3.36	3.26	3.36	3.64	2.79
2		18.55	8.35	5.19	5.10	5.84	13.91	20.41	4.82
3		10.03	4.56	4.28	5.20	7.02	10.03	4.47	4.19
4		3.87	3.69	3.78	4.50	5.12	4.68	4.68	2.97
	Correlation coefficients								
1		0.12	0.13	0.12	0.19	0.13	0.004	-0.009	0.34
2		0.002	0.009	0.011	0.002	0.002	0.006	-0.003	0.11
3		-0.004	-0.005	-0.005	-0.005	-0.005	-0.004	-0.004	0.045
4		0.27	0.32	0.32	0.016	0.004	0.010	-0.004	0.68

Table 13. COMPARISON OF OBSERVED AND CALCULATED HOURLY CONCENTRATIONS FOR OBSERVED CONCENTRATIONS GREATER THAN 200 $\mu g/m^3$

Day	Hour	Station	Flow vector (degrees)	Wind speed (m/sec)	Stability index[a]	Mixing depth (m)	Observed concentration ($\mu g/m^3$)	Calculated concentration ($\mu g/m^3$)
1	12	3	229	14.6	4	950	480	42
1	13	3	239	16.0	4	916	731	40
1	14	3	243	17.6	4	934	480	458
1	15	3	246	16.7	4	994	336	3
11	12	1	104	6.4	4	830	330	0
13	9	1	122	4.4	4	233	236	0
13	11	2	145	3.0	3	505	325	0
13	13	2	139	4.4	3	776	239	3
14	19	1	112	4.4	4	1239	242	0
14	20	1	119	4.3	4	1343	236	0
14	5	2	137	7.3	4	1189	371	0
14	6	2	137	8.2	4	1175	414	0
14	7	2	132	8.0	4	1181	308	0
14	10	2	136	5.6	4	1199	551	0
14	11	2	136	5.5	4	1206	286	0
19	13	1	97	2.1	3	632	251	0
20	3	1	104	7.6	3	680	276	0
20	5	1	110	6.5	4	637	204	0
20	6	1	114	6.5	4	621	210	0
26	8	4	314	9.3	4	898	207	1
26	9	4	300	8.1	4	887	279	0
26	11	4	307	11.4	4	894	304	0
26	12	4	316	13.9	4	893	440	78
26	15	4	309	13.0	4	891	210	1
34	10	1	110	3.3	3	1394	210	12
34	11	1	117	2.7	3	1389	250	1
36	14	4	310	12.8	4	1114	312	120
36	13	4	317	11.5	4	1114	480	23
44	14	4	303	13.1	4	31	443	0
70	21	2	134	5.6	5	1236	213	0
78	22	4	296	14.8	4	838	437	0
78	23	4	299	14.3	4	867	534	0
86	7	1	117	6.9	4	380	294	0
85	11	3	251	2.3	2	868	279	0
85	12	3	234	2.9	2	1009	443	0
86	9	3	228	14.4	4	1044	219	295
86	11	3	234	16.2	4	1030	310	2832
86	12	3	230	16.9	4	1013	389	4203
86	13	3	230	16.6	4	995	286	4494
97	13	1	118	11.8	4	1191	238	0
98	18	1	123	7.6	4	2057	218	19
104	18	1	104	9.7	4	972	206	0
104	20	1	117	7.3	4	1081	215	0
104	21	1	113	8.0	4	1146	216	2
104	22	1	119	8.6	4	1211	293	0
105	13	2	129	7.1	4	1989	210	0
154	10	1	91	3.8	4	822	279	0
154	17	1	121	13.0	4	1426	233	311
155	9	1	116	4.1	3	1137	414	5
155	10	1	97	4.2	2	1379	417	0
196	9	1	125	4.3	2	1015	216	172
219	10	1	98	3.5	2	1288	316	0
219	11	1	122	3.1	2	1537	288	243
229	10	1	105	2.5	2	633	283	1
233	9	1	114	1.3	3	637	348	0
233	10	1	79	4.5	2	799	231	0
233	11	1	72	2.8	2	961	215	0
264	13	2	149	3.8	4	1008	240	1
268	14	3	229	5.1	2	1598	207	177
283	15	4	310	11.8	4	696	318	75
290	8	3	202	8.9	4	783	207	0
298	13	4	308	8.4	4	569	211	0
298	14	4	286	8.3	4	567	276	0

[a] Stability index was determined at Quonset Point.

model predictions. The three extremely high model predictions greater than 2000 $\mu g/m^3$ are due to a model assumption of total plume downwash under high wind conditions.

A further illustration of the problems involved with an hour by hour model validation procedure is given in Figures 24 and 25 where the number of concentrations over 50 $\mu g/m^3$ for receptor 1 have been plotted as a function of flow vector for measured and calculated concentrations, respectively. The relatively broad angular range associated with the measured concentrations as compared to the predicted values could be due to errors in wind direction measurement or an unrealistic angular plume width as predicted by the model. In addition to the different distribution widths there is also the difficulty that the total number of counts is much less for the calculated distributions, indicating that even with the plume rise retardation, the vertical dispersion coefficients may still be in need of revision.

Some improvement in model predictions might be gained by incorporation of vertical dispersion coefficients developed by F. B. Smith.[10] These values were generated from a scheme which utilized numerical solutions of the diffusion equation up to 100 km downwind based upon actual measurements of wind and diffusivity profiles. The selection of stability criteria is similar to that used by Turner except that the stability index is considered to be a continuous variable with a range from 0 to 7. According to this system stability "A" would correspond to 0.5, "B" to 1.5, etc. The adoption of this continuous range of stabilities would eliminate the rather quantized pattern of concentration predictions and might lead to a better agreement with measurements.

In addition to the option of continuously varying stability indices this calculation scheme allows for the variation of vertical dispersion σ_z with surface roughness, which could conceivably change the value of σ_z by as much as 50 percent. Another factor which must be weighted in

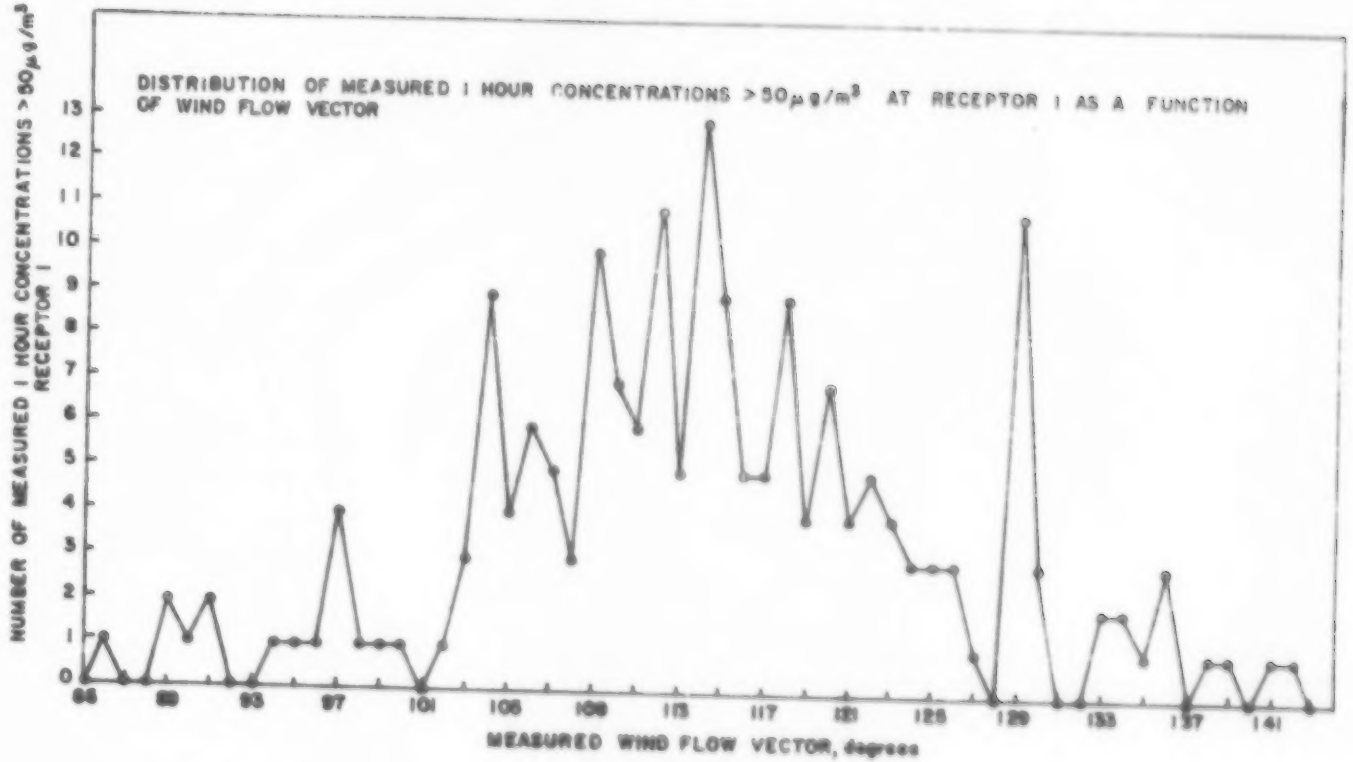

Figure 24. Distribution of measured 1 hour concentrations > 50 $\mu g/m^3$ at receptor 1 as a function of wind flow vector

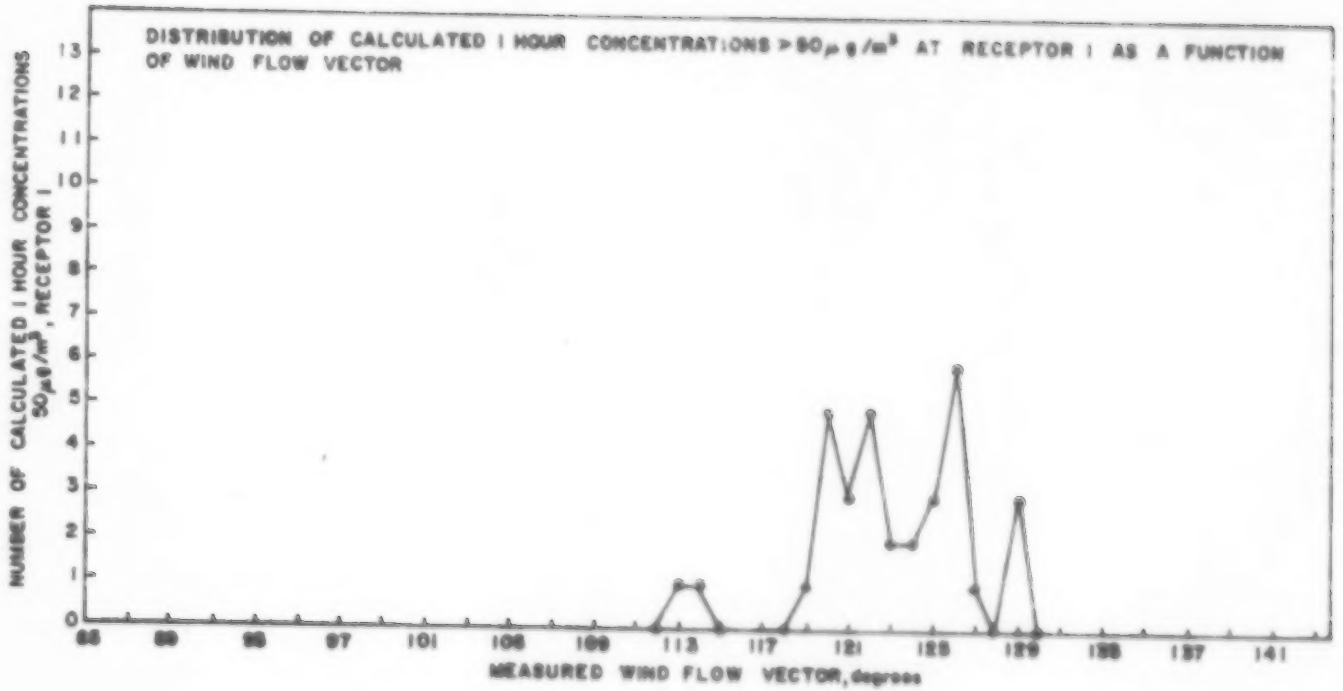

Figure 25. Distribution of calculated 1 hour concentrations > 50 $\mu g/m^3$ at receptor 1 as a function of wind flow vector

favor of testing these curves with concentration data is the considerable variation between the σ_z predictions of Smith and Turner. This discrepancy is shown in Table 14 where the values of σ_z based on both methods are compared at 4 km distance for each stability. For the Smith curves a roughness of 10 cm has been used. These differences in vertical dispersion coefficients could be important in the case of the Canal Plant due to the rather small source receptor distances.

Table 14. COMPARISON OF VERTICAL DISPERSION COEFFICIENTS (σ_z) OF SMITH AND TURNER AT A 4 KM DISTANCE WITH A SURFACE ROUGHNESS OF 10 CM

σ_z (meters)	Stability index					
	A	B	C	D	E	F
Smith	506	255	170	110	63	32
Turner	-	500	220	76	50	20

SECTION VIII

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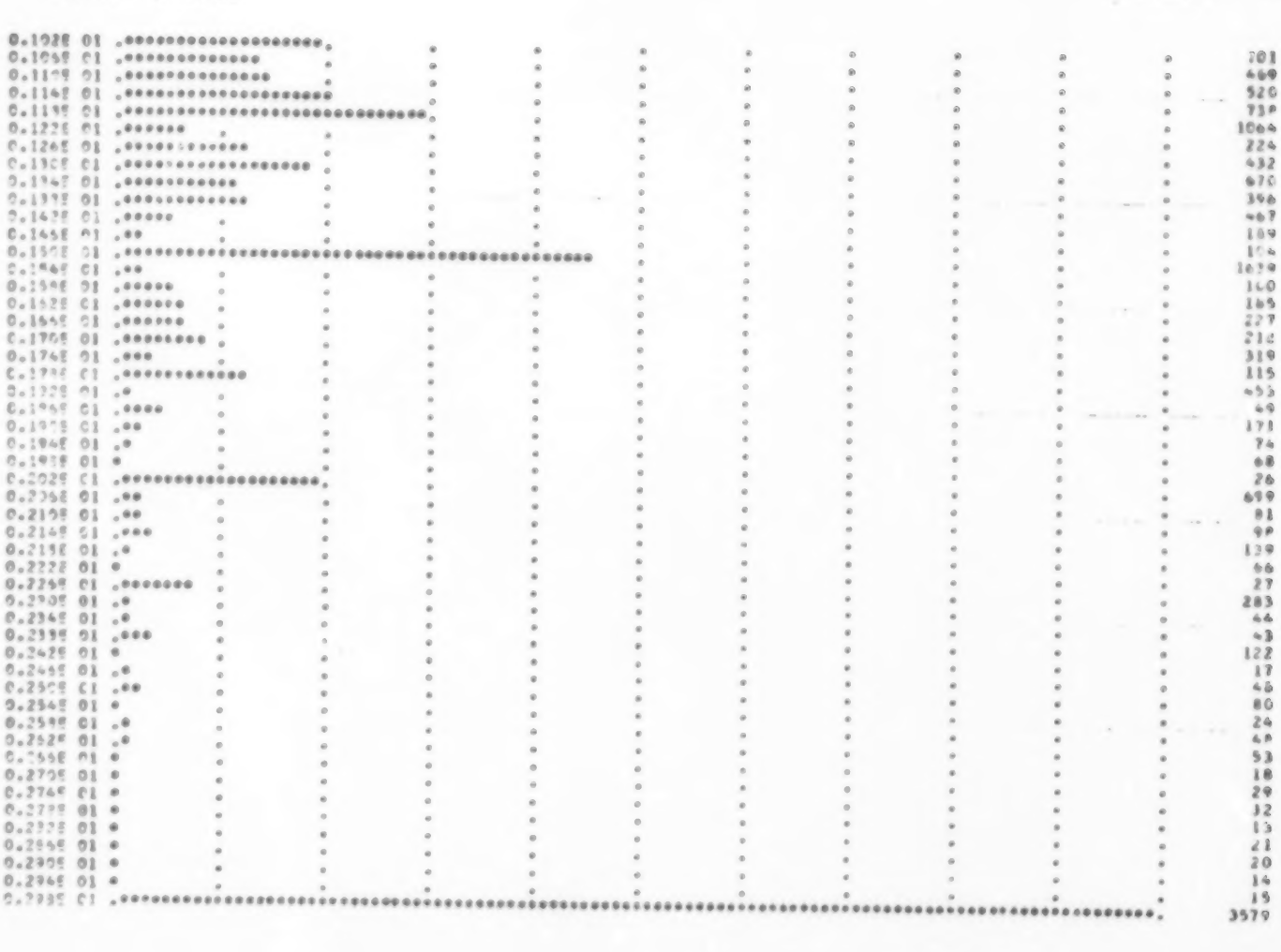
10. Smith, F. B. A Scheme for Estimating the Vertical Dispersion of a Plume From a Source Near Ground Level. Proc. 3rd Meeting of the Expert Panel on Air Pollution Modeling. A Report of the Air Pollution Pilot Study, NATO Committee on the Challenges of Modern Society. Paris, France. XVII, 1-14, October 2-3, 1972.

APPENDIX A

CONCENTRATION RATIO DISTRIBUTIONS FOR 1971

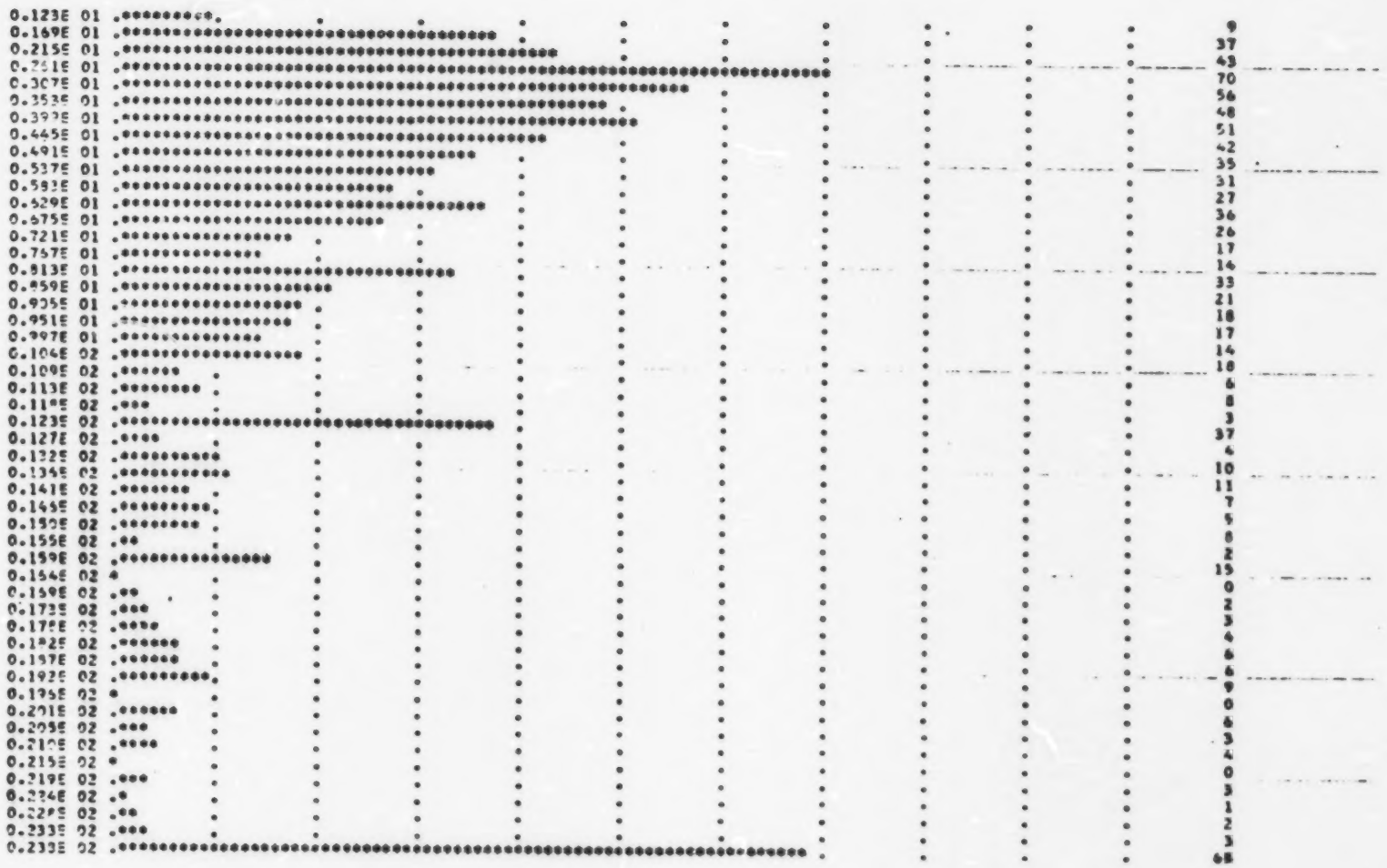
1 TO 3HR RATIOS COMBINED

Y-SCALE= 0.36E 03



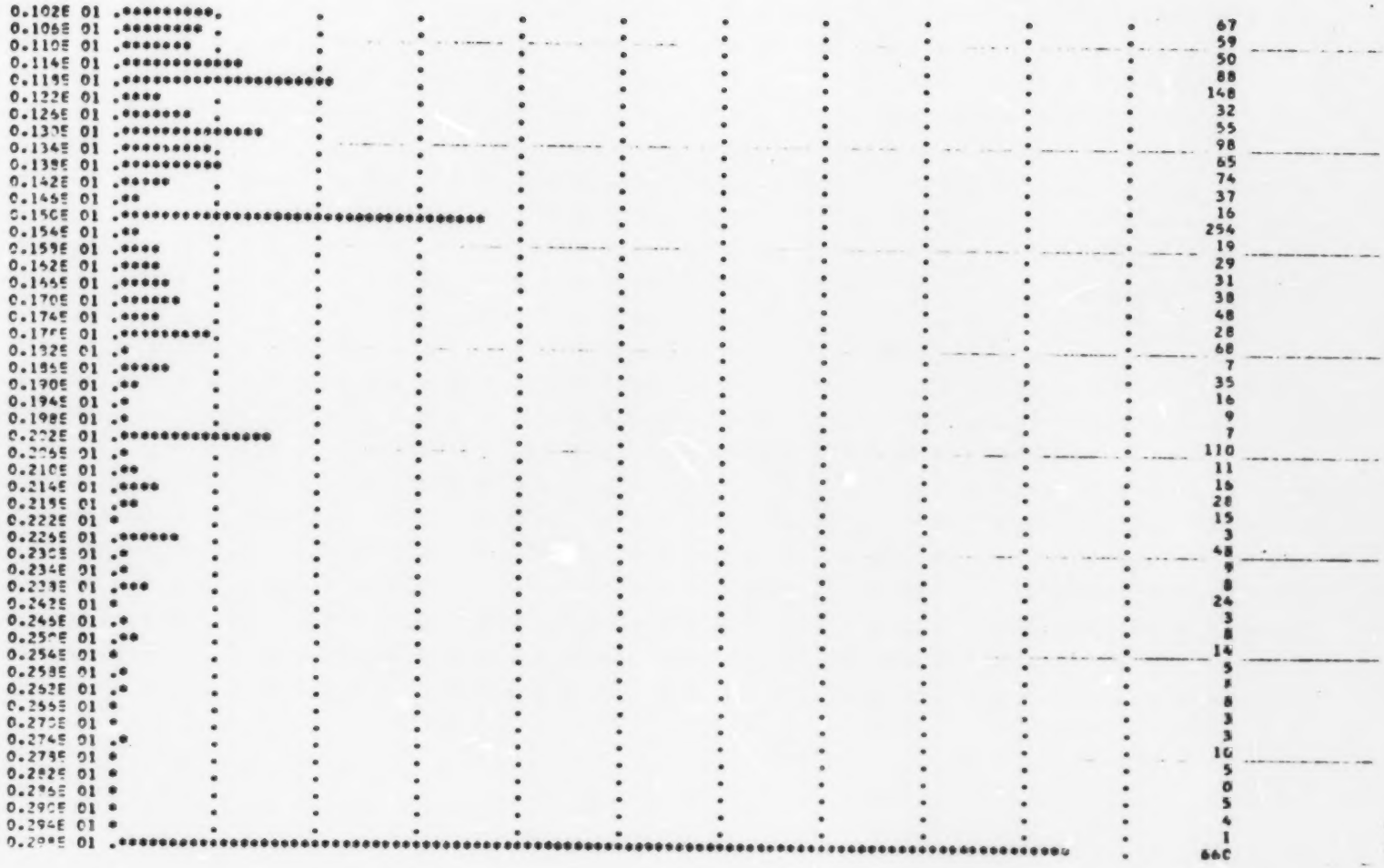
1 TO 24HR RATIOS COMBINED

Y-SCALE= 0.10E 02



JOINT WINDSPEED RATIO FREQUENCY DISTRIBUTION
1 TO 3HR RATIOS
WINDSPEED CLASS 1

Y-SCALE= 0.70E 02



| | | |

JOINT CONCENTRATION-RATIO FREQUENCY DISTRIBUTION

ABSCISSA=CONCENTRATION, ORDINATE= R1T024

CONC. BIN SIZE= 2.00

| | | |

```
0.21E 01  0  0  0  0 39  0  0  8  0 10  4  0  1  0  0  1  0  1  3  0  2  0  4  1  2  0  0  0  0  0  0  0  0  0  1  0  0  0  0  2
0.21E 01  0  0  0 75  0  0 15  0  0  5  0 10  0  7  3  0  1  1  3  0  0  1  0  1  0  0  1  0  0  0  1  0  0  0  0  0  0  1  2  1
0.22E 01  0  0  0  0  0 20  0  7  4  0  3  0  5  0  0  1  0  2  1  2  1  0  1  0  1  0  0  0  1  0  0  0  0  0  0  0  1  0  1  2
0.22E 01  0  0  0  0  0  0  0  0  0  2  0  3  0  0  0  1  0  0  0  0  0  0  4  0  0  0  0  1  0  0  0  0  0  0  2  0  1  0  0  0
0.23E 01  0182  0 42  0 18  0 12  0  6  0  2  1  3  2  1  0  0  2  1  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  2  0
0.23E 01  0  0  0  0  0  0 12  0  5  0  2  2  0  2  0  4  0  1  0  0  0  0  2  0  0  1  2  0  0  0  1  0  0  2  0  0  0  0  0  0
0.23E 01  0  0  0  0 13  0  0  6  0  6  0  1  0  0  0  1  1  0  1  0  1  1  1  0  0  1  2  0  0  0  2  1  0  0  0  2  0  0  1  1
0.24E 01  0  0 71  0  0 19  0  3  0  5  2  0  2  0  0  3  0  1  0  0  1  0  2  0  1  1  0  1  1  1  0  0  0  0  0  0  0  1  0  0
0.24E 01  0  0  0  0  0  0  0  0  4  0  0  1  0  0  0  0  0  0  1  0  0  0  0  0  2  1  1  0  0  0  1  0  1  0  0  0  0  0  0  0
0.25E 01  0  0  0  0  0 17  0  0  0  3  0  2  2  0  0  3  0  0  0  0  1  1  3  0  0  0  3  0  1  0  0  0  1  0  0  0  1  0  0  0
0.25E 01  0  0  0 52  0  0  8  0  0  4  0  0  0  2  0  1  0  0  2  0  0  0  0  0  0  0  2  1  1  1  0  0  0  0  0  0  0  0  0  0
0.25E 01  0  0  0  0  0  0  0 10  0  0  3  2  0  0  1  0  0  1  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1  0  0
0.26E 01  0  0  0 23  0  0  0  6  5  0  0  1  2  0  0  1  1  0  0  0  0  0  1  0  0  0  0  0  0  0  0  0  1  0  0  0  2  0  0  0
0.26E 01  0  0  0  0 20  0  0  0  0  7  0  0  0  1  0  0  0  1  3  0  0  0  2  0  0  0  1  1  0  0  2  0  0  1  2  0  0  2  2  0
0.27E 01  0  0  0  0  0  3  0  0  0  1  0  0  0  0  0  3  3  0  0  1  1  1  0  0  0  0  0  0  0  1  0  0  1  0  0  0  0  0  0  0
0.27E 01  0  0  0  0  0 12  0  0  0  0  0  2  0  0  0  0  0  1  3  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  1  0  2
0.27E 01  0  0  0  0  0  0  5  7  0  0  0  0  0  2  4  0  0  0  0  2  3  1  0  0  0  1  1  0  1  0  0  0  0  1  1  0  0  0  0  0
0.28E 01  0  0  0  0  0  0  0  2  1  3  0  0  0  0  0  0  1  0  1  0  0  0  0  0  1  0  0  0  0  0  0  0  0  1  0  0  0  0  0  0
0.28E 01  0  0  0  0  0  0  0  0  0  1  2  0  0  0  0  0  0  0  0  0  1  2  1  0  0  0  0  0  0  2  1  0  0  1  1  0  0  0  1  0
0.29E 01  0  0  0  0  0  0  0  0  0  0  0  2  1  4  3  1  0  0  0  0  0  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0.29E 01  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1  0  1  0  0  0  1  0  0  0  0  0  0  0  0  0  1  0  1  0  0  0  0  1
0.29E 01  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1  0  0  0  0  0  2  0  0  2  0  0  0  0  2  0
0.30E 01******219247102116 25 72 13 40 19 24  9 19  7 14  5 13 13  2  9  9  7  4 10  3  4  6  2  2  4  0  3  1  3  2  4  5  1  1
```

JOINT CONCENTRATION-RATIO FREQUENCY DISTRIBUTION

ABSCISSA=CONCENTRATION, ORDINATE= R1T03

CONC. BIN SIZE= 2.00

```
0.10E 01 92270 96 97 16 53 30 29  4  3  2  0  0  1  5  1  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0.11E 01  0  0 0206 63 92 27 26  8 26  5  0  1  6  1  2  0  0  1  0  0  0  1  0  1  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0
0.11E 01  0 0162  0125 79 35 35 27 18  6  4  5  0  0  4  2  2  2  0  1  0  0  0  1  0  0  0  3  0  0  1  0  1  0  0  0  0  0  0  0
0.11E 01 0136  0314  0131 36 41  4 29  8  9  1  4  2  2  1  0  2  1  0  0  1  0  1  0  2  0  2  0  0  0  0  0  0  0  0  1  0  0
0.12E 01 0259253143 83101 41 91 17 23 15  4  6  7  3  6  0  1  1  1  0  0  0  3  1  0  0  0  0  0  0  1  0  1  0  0  0  0  0  0
0.12E 01  0  0  0  0 91 42  0 21 12 15  7  3  6  1  3  1  0  2  4  2  1  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  0  1  1  0  0
0.13E 01  0  0 0212  0 53 24 43 12 19  4 17  1 11  2  2  1  2  4  1  0  0  4  2  2  0  1  0  0  0  0  2  0  0  1  0  2  0  0  0
0.13E 01 0278  0104 84 46 29 44 10 18  2 10  5  3  2  3  2  1  3  1  0  3  0  1  1  1  0  0  1  0  1  0  0  2  0  0  3  0  0  1
0.13E 01  0 0197  0  0 91  0 14 13 18  2 10  7  3  2  8  0  1  2  2  0  0  3  0  2  0  1  0  2  0  0  1  0  0  1  0  1  0  2  0
0.14E 01  0  0 0244 62  0 33 43 11 18  5  4  2  6  1  1  2  5  4  1  2  2  0  0  0  1  2  0  1  0  0  0  0  1  1  0  0  0  0  0
0.14E 01  0  0  0  0  0 77 18 22  0 11  7  9  1  3  5  5  1  0  4  0  1  0  2  3  1  0  1  0  0  1  0  0  0  0  0  0  0  1  0  1
0.15E 01  0  0  0  0  0  0  0  0 11 17  4 12  7  4  1  6  5  2  3  1  0  0  2  3  2  1  0  1  1  1  0  0  0  1  1  0  2  0  0  0
0.15E 0139063418*4198 56 68 27 20  6  7  4  7  3  2  1  2  0  0  2  0  0  1  0  1  0  1  1  0  1  1  2  0  0  0  0  0  1  0  0  0
0.15E 01  0  0  0  0  0  0  0  0 10 15  6  6  1  4  2  3  1  7  3  0  0  0  4  0  2  0  2  1  1  1  1  1  0  1  0  0  0  1  0  1
0.16E 01  0  0  0  0  0 58 18 38  0  0  6 12  2  0  4  7  3  1  1  0  0  1  1  0  3  2  1  2  1  0  2  0  2  1  1  0  0  0  1  0
0.16E 01  0  0  0 93 48  0  0 18 12 12  0  5  3  1  1  3  1  0  2  0  0  0  1  1  4  0  1  0  1  0  3  0  0  0  2  0  1  0  1  0
0.17E 01  0  0 0117  0  0 26 13  0  7  6  5  0  0  3  0  1  4  4  0  1  1  3  3  3  0  1  0  0  1  0  0  0  0  0  0  0  0  0  1
0.17E 01  0 0159  0  0 75  0  8  7  0 10 10  0  7  2  5  1  2  2  0  0  0  0  0  2  0  2  0  0  0  1  0  0  0  0  1  1  0  2  1
0.17E 01  0  0  0  0 42  0  0 20  0 13  0  8  2  1  1  1  1  0  0  2  2  1  2  0  1  0  0  0  2  0  2  0  0  0  0  0  0  0  0  1
0.1*E 01 0252  0 70  0 31 16  5 12  9  5  1  0  6  4  2  1  1  2  1  0  1  0  0  0  1  0  0  0  1  2  2  0  3  0  0  2  0  1  1
0.18E 01  0  0  0  0  0  0  0  9  0  4  0  3  3  2  2  1  0  1  3  0  0  0  0  0  2  2  0  0  0  0  3  0  0  1  0  0  1  0  3  0
0.19E 01  0  0  0 39  0 24 15  0  6  6  6  2  0  3  0  3  1  1  0  1  1  0  1  0  1  1  0  0  2  1  0  0  0  0  1  0  0  0  0  0
0.19E 01  0  0  0  0 24  0  0  7  0  7  5  1  3  0  2  4  0  1  4  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  2  0  0  2  0  2  1
0.19E 01  0  0  0  0  0 17  0  9  4  5  0  2  0  2  0  2  0  2  1  1  0  2  0  2  0  0  1  0  0  0  1  0  1  0  0  0  1  1  0  0
0.20E 01  0  0  0  0  0  0  0  0  0  0  0  0  2  3  1  0  3  2  0  1  0  0  0  2  1  0  0  0  0  0  0  0  0  0  0  0  0  1  1  0
0.20E 01 0434130 44  0 13 20  1  0  5  9  2  0  5  2  3  0  1  1  1  2  0  1  0  3  1  3  1  1  2  0  0  1  6  0  0  2  0  0  1
0.21E 01  0  0  0  0  0 21  0 16  5  5  0  5  0  0  2  3  0  0  2  0  3  1  0  0  1  1  2  0  0  0  1  0  0  0  0  3  1  0  0  1
```

0.14E 02	0	0	0	0	0	0	0	0	0	0	0	2	2	1	2	0	0	0	0	0	0	0	0	0	
0.15E 02	0	0	1	0	0	1	0	0	1	2	0	0	1	0	0	1	0	1	0	0	0	0	0	1	
0.15E 02	1	0	0	0	1	0	0	0	1	0	1	0	0	2	0	1	0	0	0	0	0	0	0	1	
0.15E 02	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	
0.16E 02	0	1	0	1	1	0	0	1	0	0	4	1	0	1	0	0	2	0	1	0	1	0	0	1	
0.16E 02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0.17E 02	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	
0.17E 02	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
0.18E 02	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	1	0	0	0	
0.19E 02	0	1	0	1	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	
0.19E 02	0	0	0	0	1	0	0	0	1	0	1	0	1	0	0	0	0	0	2	0	0	0	0	0	
0.19E 02	0	0	0	0	1	1	0	1	0	2	1	1	0	0	0	0	0	1	0	1	0	0	0	0	
0.20E 02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0.20E 02	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	1	1	
0.21E 02	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	
0.21E 02	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	
0.21E 02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0.22E 02	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	
0.22E 02	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0.23E 02	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	
0.23E 02	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
0.24E 02	2	4	1	3	1	2	5	7	5	5	2	5	3	2	1	2	0	3	1	0	5	2	5	2	

JOINT HOUR-RATIO FREQUENCY DISTRIBUTION

ABSCISSA= HOUR, ORDINATE= RITO24

0.12E 01	0	0	0	0	1	0	0	1	0	1	1	0	0	0	0	0	1	0	0	2	0	1	0	1
0.17E 01	3	2	1	1	1	1	1	0	1	1	2	2	2	2	3	2	1	0	2	0	1	2	3	3
0.21E 01	0	1	3	0	1	3	3	4	3	3	2	1	5	0	0	1	1	3	0	1	0	2	4	2
0.26E 01	2	3	0	0	3	3	3	5	6	4	1	4	3	4	1	3	2	5	3	4	4	2	2	3
0.31E 01	2	2	1	1	2	3	1	4	5	4	2	2	4	1	2	1	5	2	2	3	1	1	2	3
0.35E 01	1	1	3	1	3	0	2	3	2	3	1	0	5	3	3	1	1	2	2	1	2	2	2	4
0.40E 01	5	0	2	1	3	4	0	2	4	5	1	1	2	2	2	0	2	1	1	2	0	1	5	1
0.44E 01	0	3	0	1	4	3	0	5	0	4	0	1	2	5	2	1	2	0	4	0	1	2	2	0
0.49E 01	1	0	1	2	0	0	1	3	1	2	0	2	2	3	0	0	0	3	3	1	2	1	4	3
0.54E 01	2	1	2	2	1	1	0	1	3	3	1	1	2	0	1	1	0	0	0	0	1	2	4	2
0.58E 01	1	2	0	0	1	2	0	2	2	1	0	1	1	3	2	1	2	0	1	0	1	1	2	1
0.63E 01	1	0	1	1	0	0	2	3	1	5	3	4	1	1	1	0	3	1	0	3	1	1	2	1
0.67E 01	2	1	1	2	0	0	3	1	0	1	1	1	1	3	1	1	3	1	0	1	1	0	0	1
0.72E 01	0	0	0	0	0	0	2	5	2	0	1	0	1	1	0	1	1	0	0	0	0	1	2	0
0.77E 01	0	0	1	0	0	0	2	1	2	2	1	0	0	0	0	0	0	0	2	1	2	0	0	0
0.81E 01	0	2	0	2	1	0	1	1	2	4	5	0	1	1	2	1	1	3	1	1	3	0	0	1
0.86E 01	1	2	0	1	2	2	0	1	2	0	1	0	1	0	2	1	1	0	0	1	1	0	1	1
0.90E 01	3	0	1	2	0	0	1	0	0	1	2	1	1	0	1	1	0	1	0	0	1	0	1	1
0.95E 01	1	2	1	0	1	0	1	0	1	1	1	1	0	0	0	2	0	1	0	0	1	2	0	1
0.10E 02	0	0	0	1	1	0	0	2	0	1	1	1	0	0	1	0	2	0	2	0	1	0	0	1
0.10E 02	1	1	1	1	1	0	1	0	1	2	0	0	2	2	0	1	0	1	0	1	0	1	0	1
0.11E 02	0	0	0	0	0	0	1	2	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0
0.11E 02	0	0	0	0	0	0	1	0	1	0	0	2	0	1	1	2	0	0	0	0	0	0	0	0
0.12E 02	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.12E 02	1	3	1	1	0	1	2	5	1	0	2	1	3	1	0	2	2	1	0	2	2	0	1	5
0.13E 02	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1
0.13E 02	0	1	1	1	0	1	0	1	1	0	0	0	1	1	0	0	0	0	0	1	0	1	0	0
0.14E 02	0	0	0	0	0	0	0	0	1	1	0	0	0	2	2	0	0	3	0	0	1	0	0	1

0.21E 01	7	5	3	7	6	4	9	6	10	2	7	9	7	9	12	4	4	3	4	1	3	5	6	6
0.22E 01	2	1	1	1	5	0	3	3	5	6	3	3	9	1	1	2	2	3	3	1	5	1	4	1
0.22E 01	1	1	0	3	1	1	0	1	1	2	1	3	2	2	1	1	1	0	3	1	0	1	0	0
0.23E 01	14	10	11	16	15	8	14	9	13	16	17	9	13	11	12	18	9	10	13	11	11	6	11	6
0.23E 01	2	2	2	1	1	0	2	4	1	5	4	0	1	2	3	3	3	1	0	3	4	0	0	0
0.23E 01	1	3	0	2	2	4	0	4	1	3	3	3	3	0	2	3	0	0	4	1	0	1	3	0
0.24E 01	5	7	3	5	6	2	7	10	3	4	9	6	5	2	3	5	6	4	4	5	5	1	11	4
0.24E 01	0	1	0	0	2	1	0	1	2	3	0	1	2	1	0	1	1	0	0	0	0	0	1	0
0.25E 01	2	1	1	0	0	0	2	2	2	2	4	2	8	5	3	2	2	2	2	2	3	1	0	0
0.25E 01	4	2	4	5	3	4	1	10	5	2	0	6	2	5	2	6	0	3	2	7	0	2	2	3
0.25E 01	0	1	0	1	1	2	0	2	0	2	3	1	1	1	2	1	1	0	0	2	1	0	2	0
0.26E 01	0	2	0	1	0	2	2	1	5	5	4	6	1	1	2	2	0	3	2	0	3	0	2	4
0.26E 01	1	3	3	0	1	2	4	4	4	2	4	1	3	3	1	3	1	0	3	1	2	3	4	0
0.27E 01	1	2	1	1	1	1	1	0	1	0	0	1	4	0	0	0	0	0	0	0	1	0	2	1
0.27E 01	0	0	0	0	0	2	0	2	2	0	3	5	2	2	0	2	0	1	1	1	0	1	1	4
0.27E 01	1	3	1	1	1	1	0	1	2	3	5	0	3	0	2	0	2	0	0	1	0	2	1	2
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0.29E 01	1	0	0	0	1	0	0	2	2	2	3	1	4	2	1	0	0	1	0	0	0	0	0	0
0.29E 01	0	0	0	0	1	0	0	0	1	3	0	1	2	1	1	3	1	0	0	0	0	0	0	0
0.29E 01	1	1	0	1	0	0	0	0	0	3	3	1	1	2	1	0	0	0	1	0	0	0	0	0
0.30E 01	154	166	118	139	150	130	161	189	176	213	172	166	157	152	118	137	122	194	119	131	151	108	191	145

JOINT HOUR-RATIO FREQUENCY DISTRIBUTION

ABSCISSA= HOUR, ORDINATE= RITO3

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0.11E 01	19	27	22	20	28	24	23	16	20	11	5	9	15	17	17	15	19	15	22	31	15	35	17	28
0.11E 01	14	23	31	26	21	25	15	16	16	13	16	16	15	1*	1*	22	25	24	33	29	24	29	34	17
0.11E 01	33	32	42	25	37	30	24	29	23	28	19	19	21	32	28	40	31	36	43	41	36	27	30	32
0.12E 01	52	42	44	53	54	38	48	40	41	40	28	35	29	36	41	52	54	47	53	41	48	55	51	42
0.12E 01	6	7	14	9	9	8	6	10	10	9	4	7	13	12	4	7	6	10	14	12	8	13	14	12
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0.20E 01	25	22	29	24	31	33	30	33	30	30	24	35	30	26	39	29	27	27	30	27	31	37	21	29
0.21E 01	2	4	3	0	5	4	3	2	2	4	5	3	4	4	4	8	3	4	4	4	2	2	5	0
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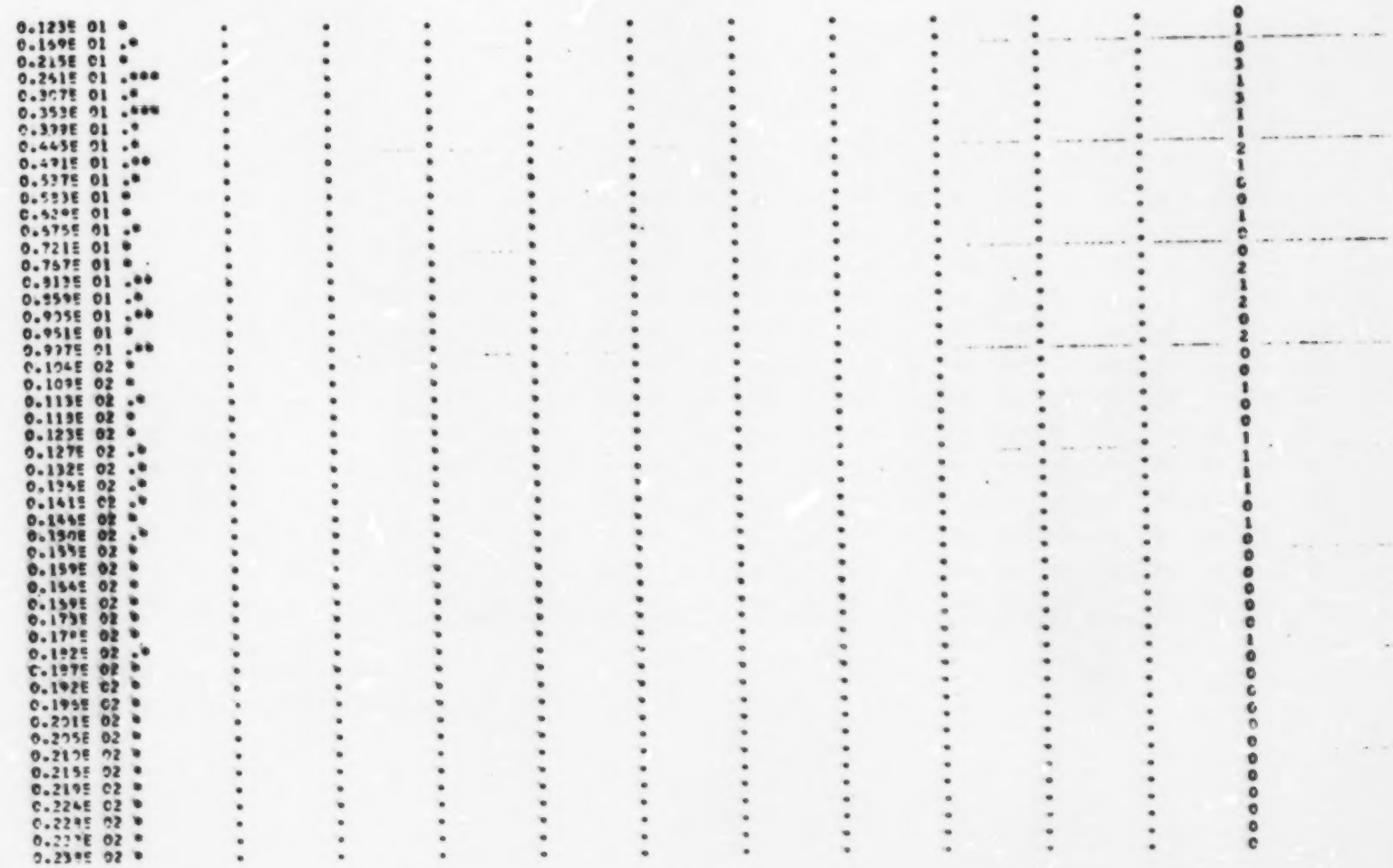
JOINT DIRECTION RATIO FREQUENCY DISTRIBUTION
1 TO 24HR RATIOS
DIRECTION 3---112 TO 152 DEGREES

Y-SCALE= 0.10E 02



JOINT DIRECTION RATIO FREQUENCY DISTRIBUTION
1 TO 24HR RATIOS
DIRECTION 3--024 TO 064 DEGREES

Y-SCALE= 0.10E 02

JOINT DIRECTION RATIO FREQUENCY DISTRIBUTION
1 TO 24HR RATIOS
DIRECTION 2--29° TO 338 DEGREES

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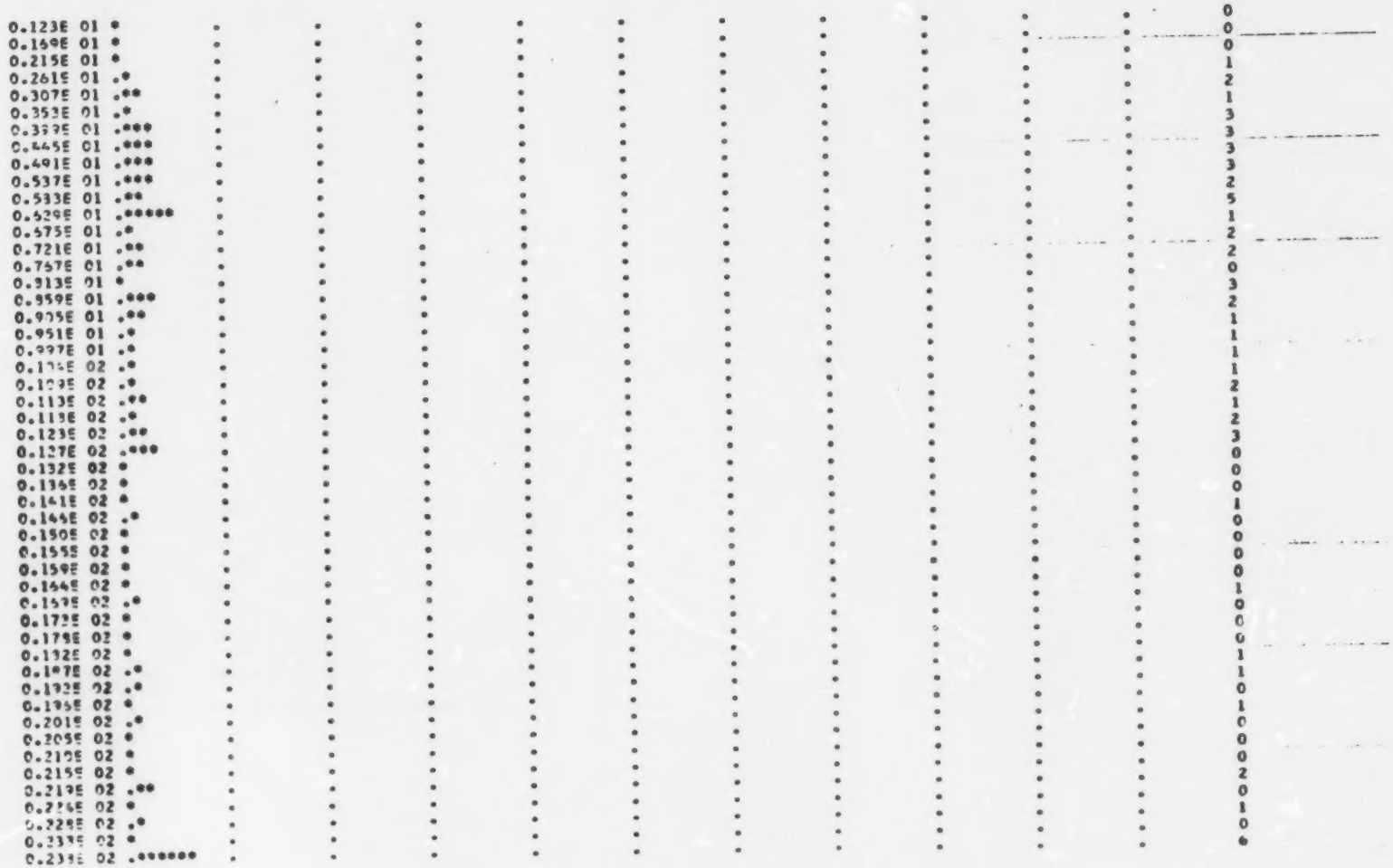

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1 TO 24HR RATIOS
DIRECTION 1--279 TO 319 DEGREES

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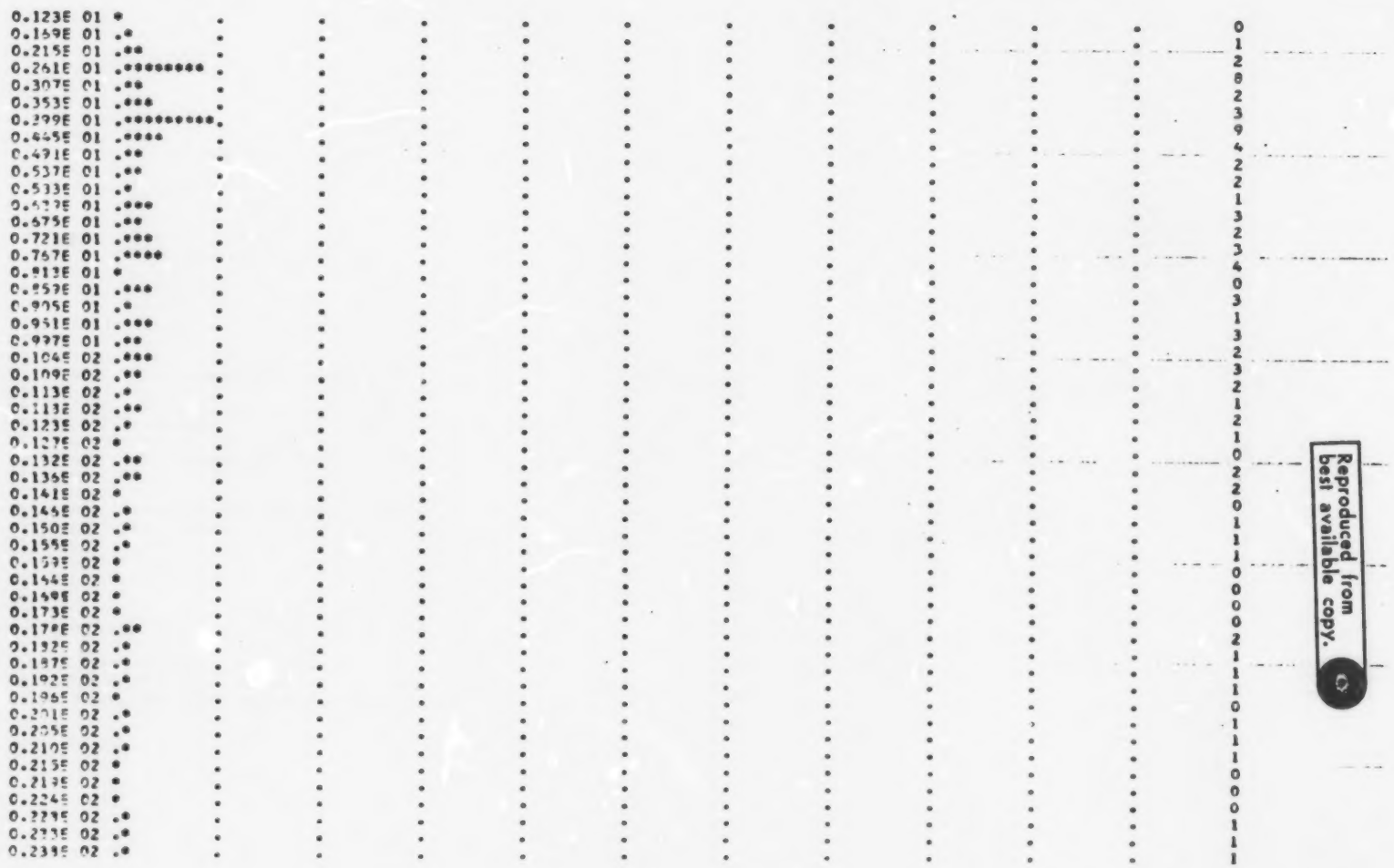

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JOINT DIRECTION RATIO FREQUENCY DISTRIBUTION
1 TO 3HR RATIOS
DIRECTION 3—112 TO 152 DEGREES

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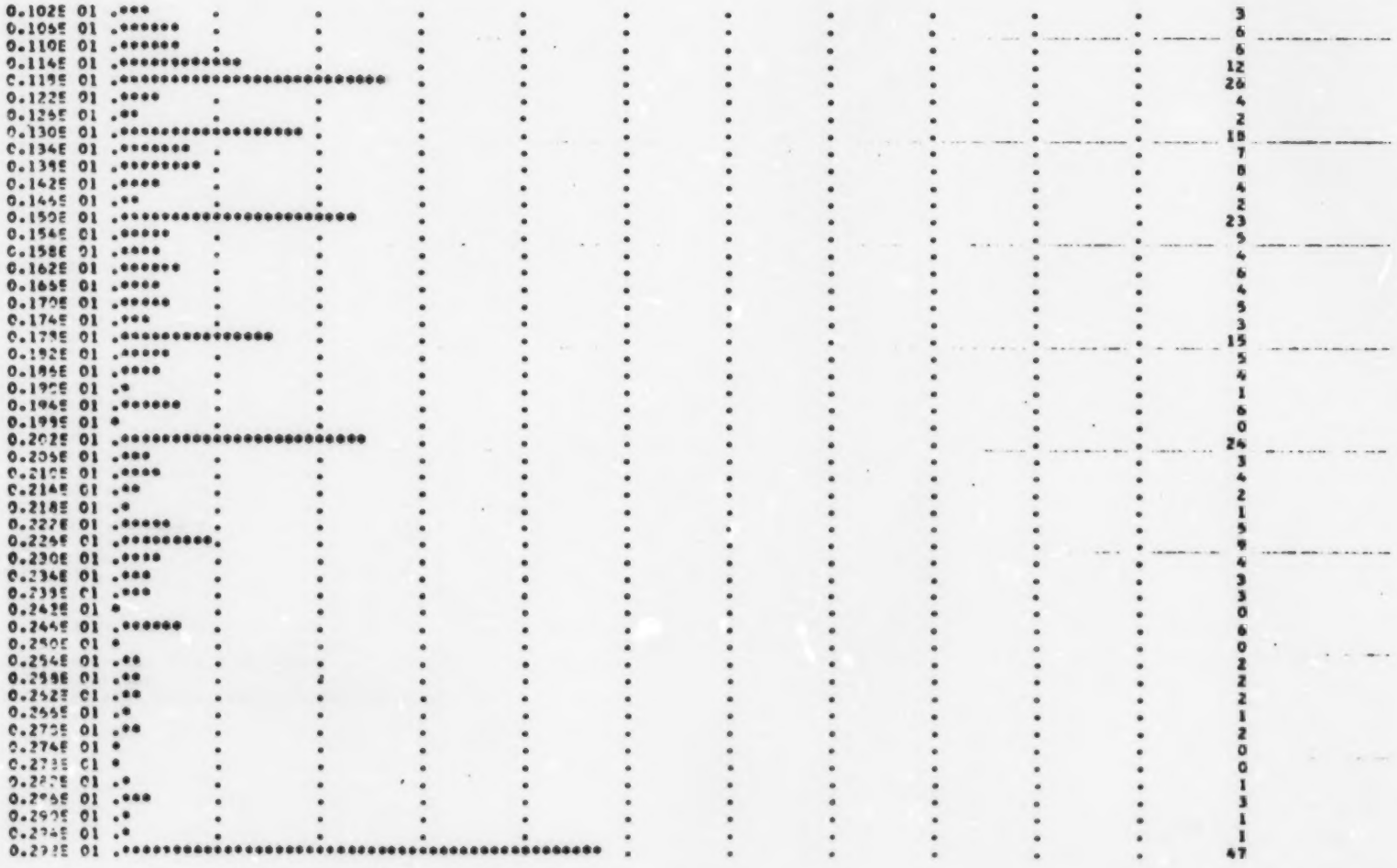

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1 TO 3HR RATIOS
DIRECTION 3—024 TO 064 DEGREES

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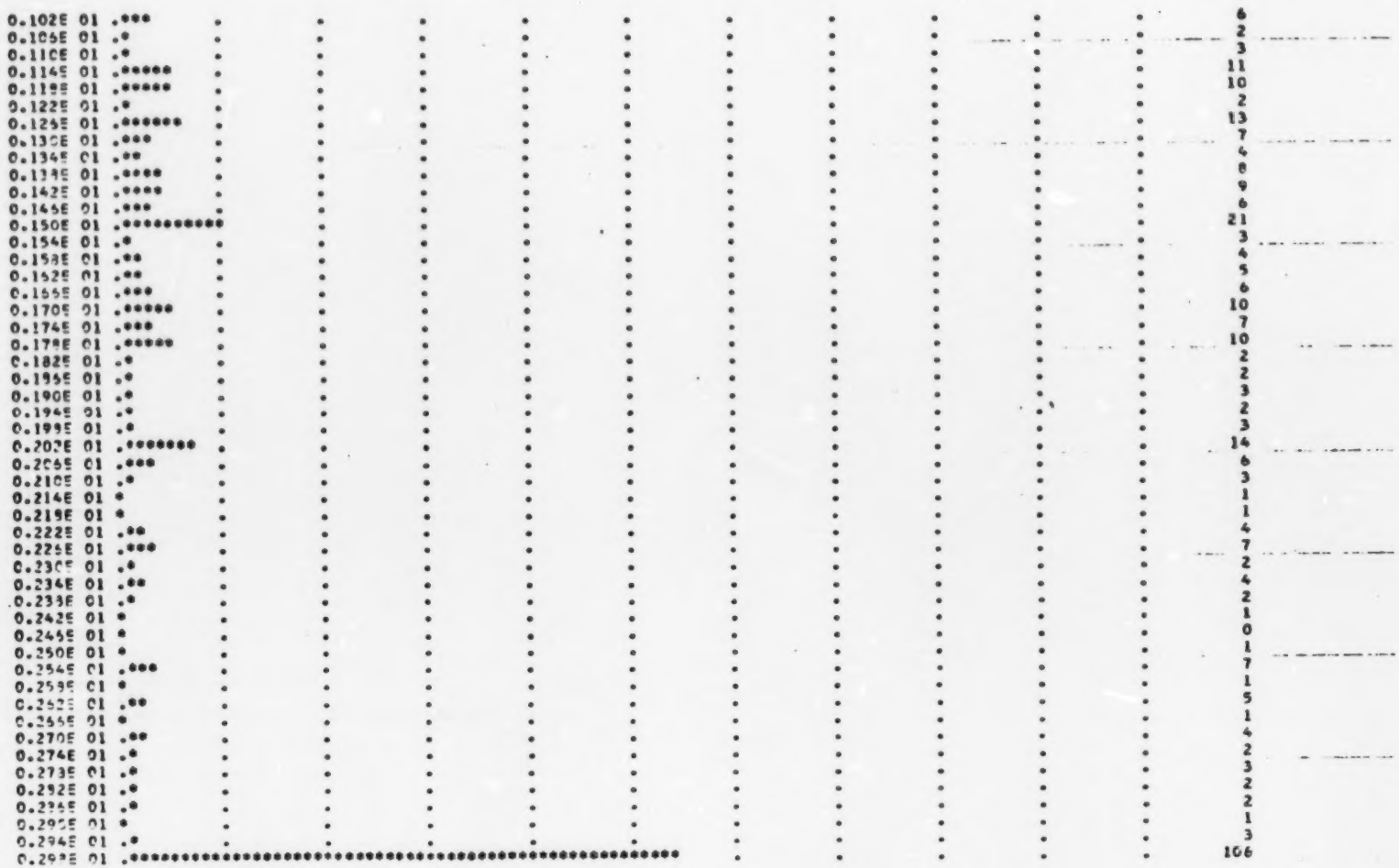

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1 TO 3HR RATIOS
DIRECTION 2—299 TO 338 DEGREES

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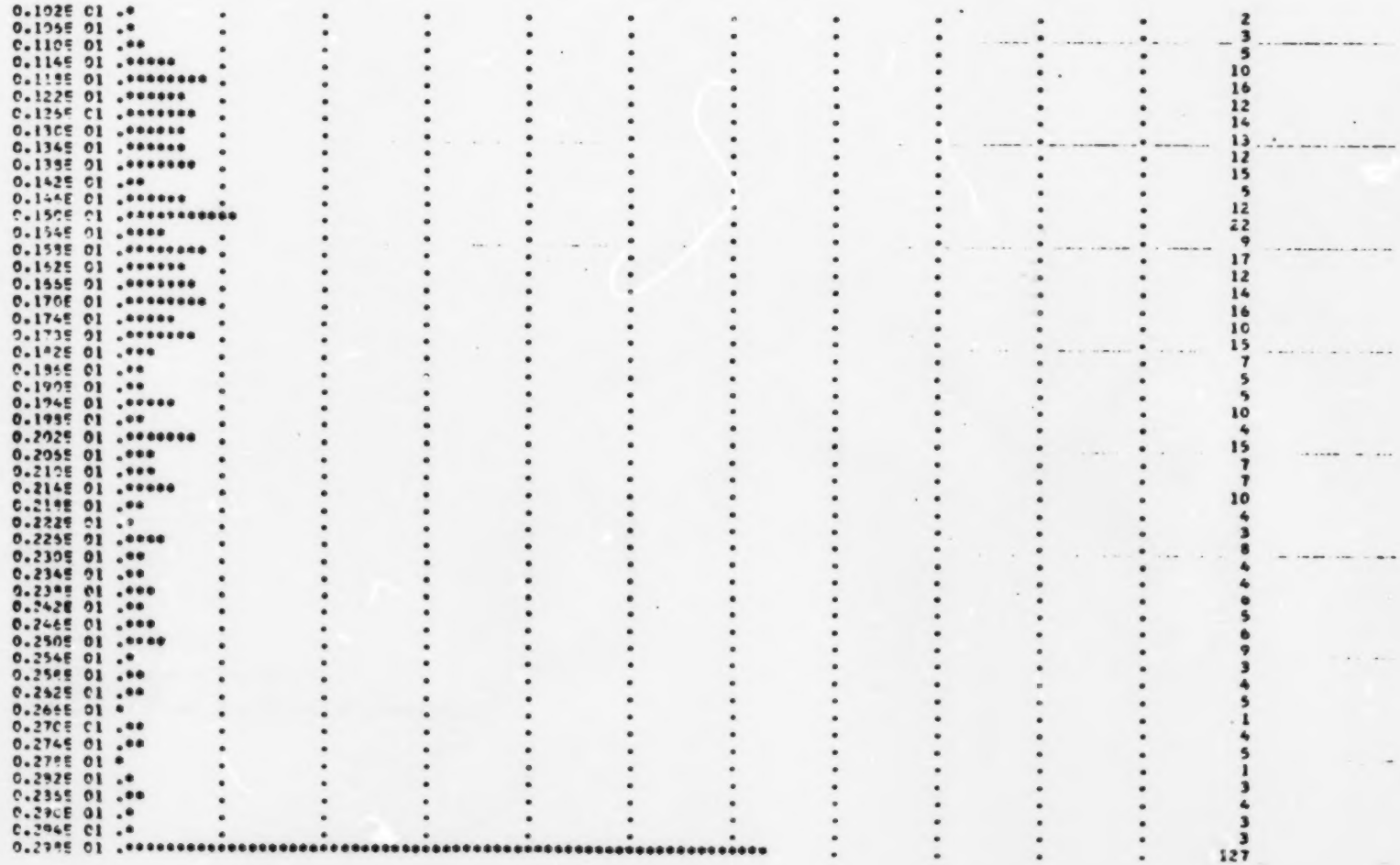

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1 TO 3HR RATIOS
DIRECTION 1--279 TO 319 DEGREES

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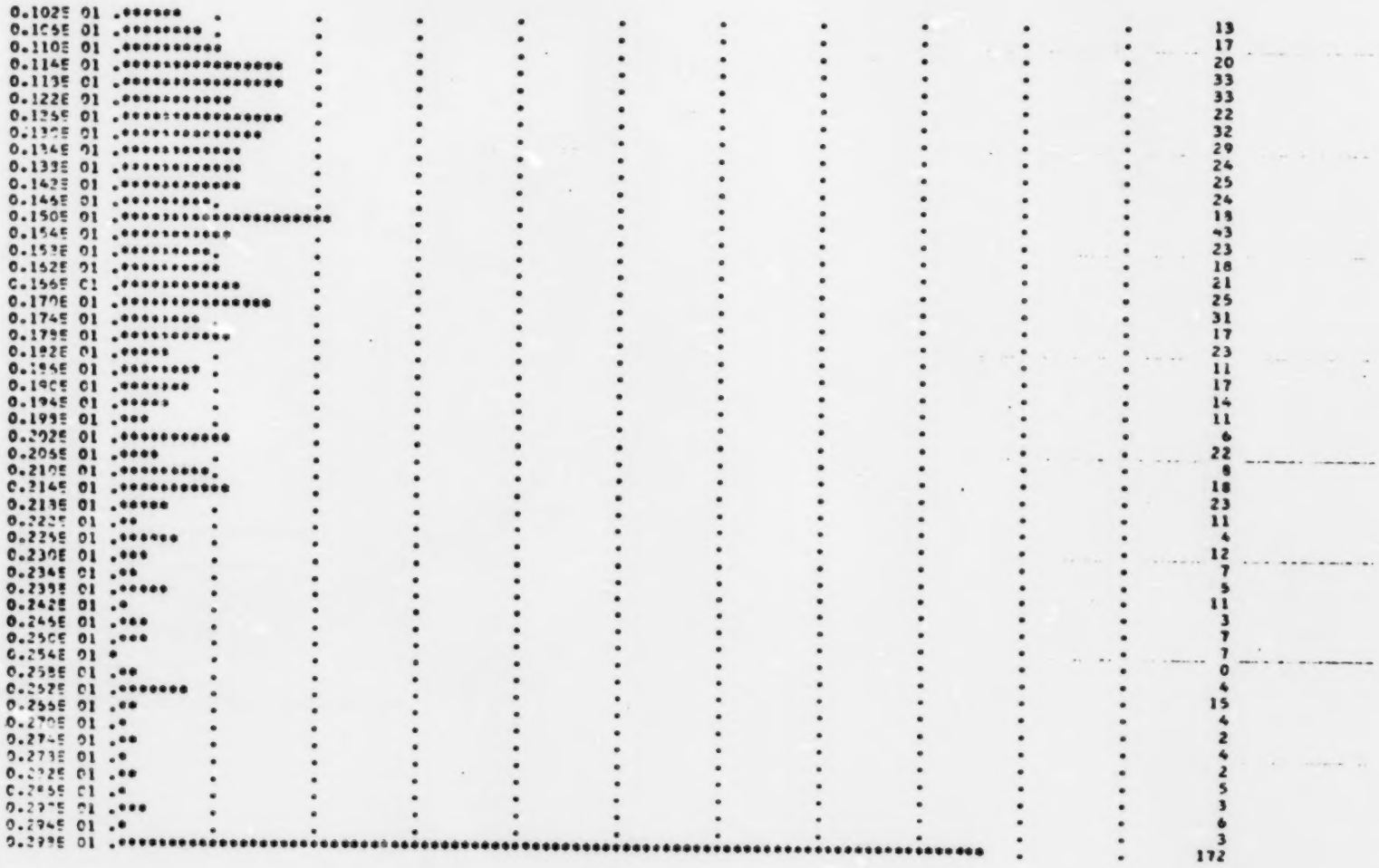
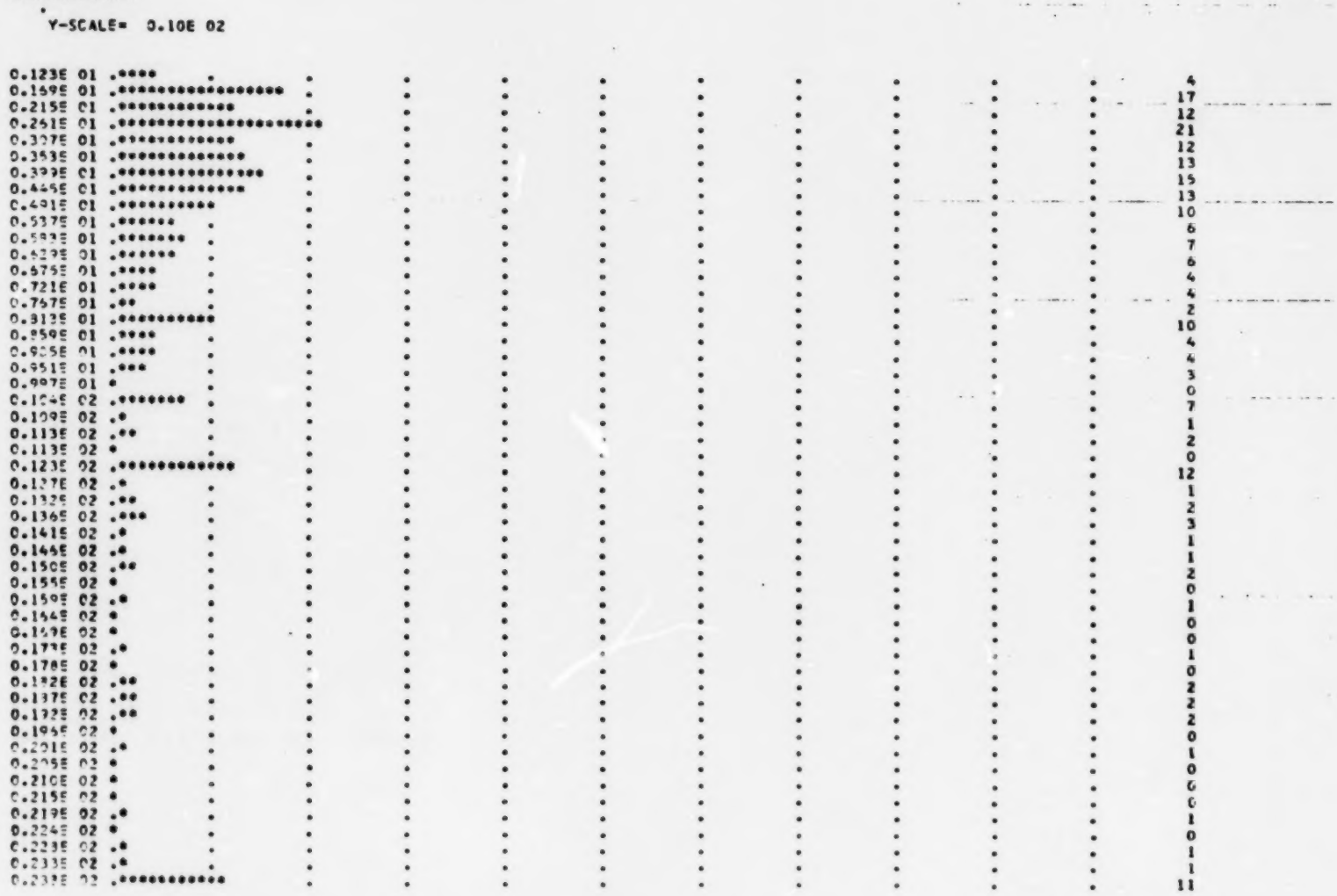


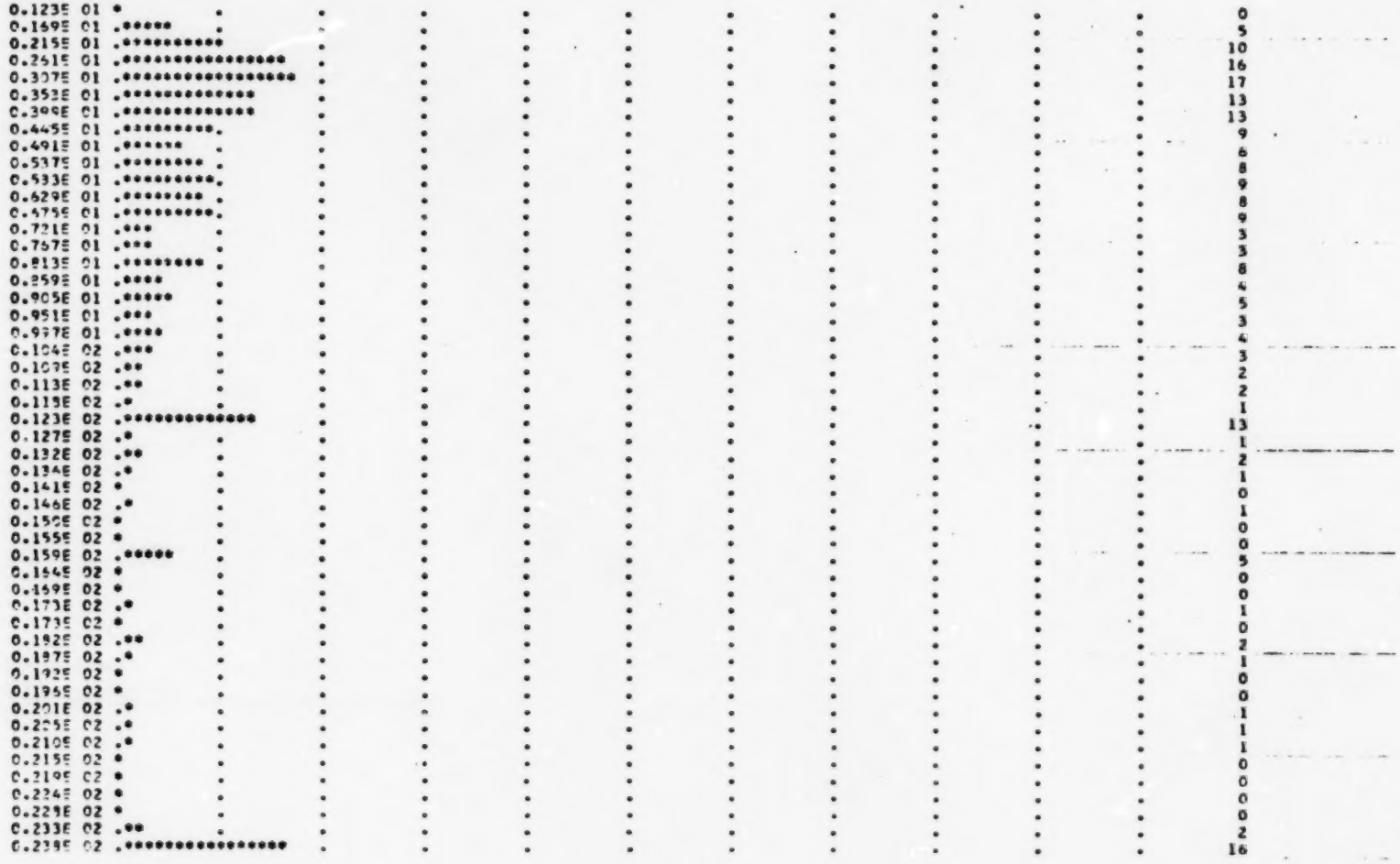
JOINT SEASON-RATIO FREQUENCY DISTRIBUTION
1 TO 24HR RATIOS
SEASON=AUTUMN

Y-SCALE= 0.10E 02



JOINT SEASON-RATIO FREQUENCY DISTRIBUTION
1 TO 24HR RATIOS
SEASON=SUMMER

Y-SCALE= 0.10E 02



JOINT SEASON-RATIO FREQUENCY DISTRIBUTION
1 TO 24HR RATIOS
SEASON=SPRING

Y-SCALE= 0.10E 02

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0.169E 01 .***********                                                       11
0.215E 01 .**************                                                    13
0.261E 01 .*****************                                                 16
0.307E 01 .**********.                                                        9
0.353E 01 .**********                                                        10
0.399E 01 .**************                                                    13
0.445E 01 .********                                                           8
0.491E 01 .********                                                           8
0.537E 01 .*******                                                            7
0.583E 01 .******                                                             6
0.629E 01 .*****************                                                16
0.675E 01 .********                                                           8
0.721E 01 .******                                                             6
0.767E 01 .****                                                               4
0.813E 01 .***********                                                       11
0.859E 01 .*****                                                              5
0.905E 01 .*****                                                              5
0.951E 01 .********                                                           8
0.997E 01 .*****                                                              5
0.104E 02 .****                                                               4
0.109E 02 .**                                                                 2
0.113E 02 .**                                                                 2
0.118E 02 .*                                                                  1
0.123E 02 .*******                                                            7
0.127E 02 .**                                                                 2
0.132E 02 .****                                                               4
0.136E 02 .***                                                                3
0.141E 02 .****                                                               4
0.145E 02 .***                                                                3
0.150E 02 .***                                                                3
0.155E 02 .*                                                                  1
0.159E 02 .******                                                             6
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0.169E 02 .*                                                                  1
0.173E 02 .*                                                                  1
0.178E 02 .**                                                                 2
0.182E 02 *                                                                   0
0.187E 02 .***                                                                3
0.192E 02 .***                                                                3
0.196E 02 *                                                                   0
0.201E 02 .***                                                                3
0.205E 02 *                                                                   0
0.210E 02 .*                                                                  1
0.215E 02 *                                                                   0
0.219E 02 .*                                                                  1
0.224E 02 *                                                                   0
0.228E 02 .*                                                                  1
0.233E 02 *                                                                   0
0.238E 02 .************************                                      25
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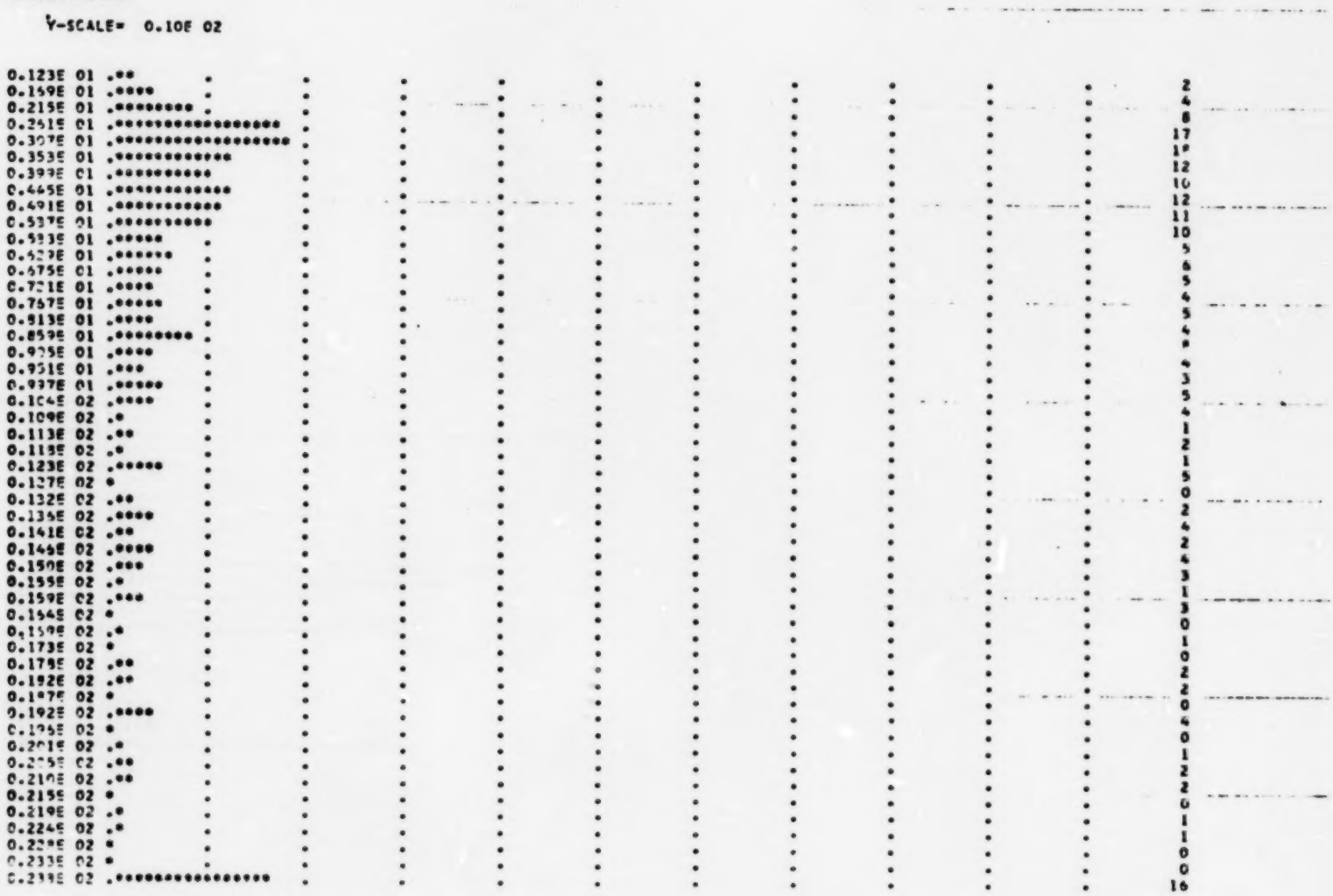
1 TO 24HR RATIOS
SEASON=WINTER

Y-SCALE= 0.10E 02



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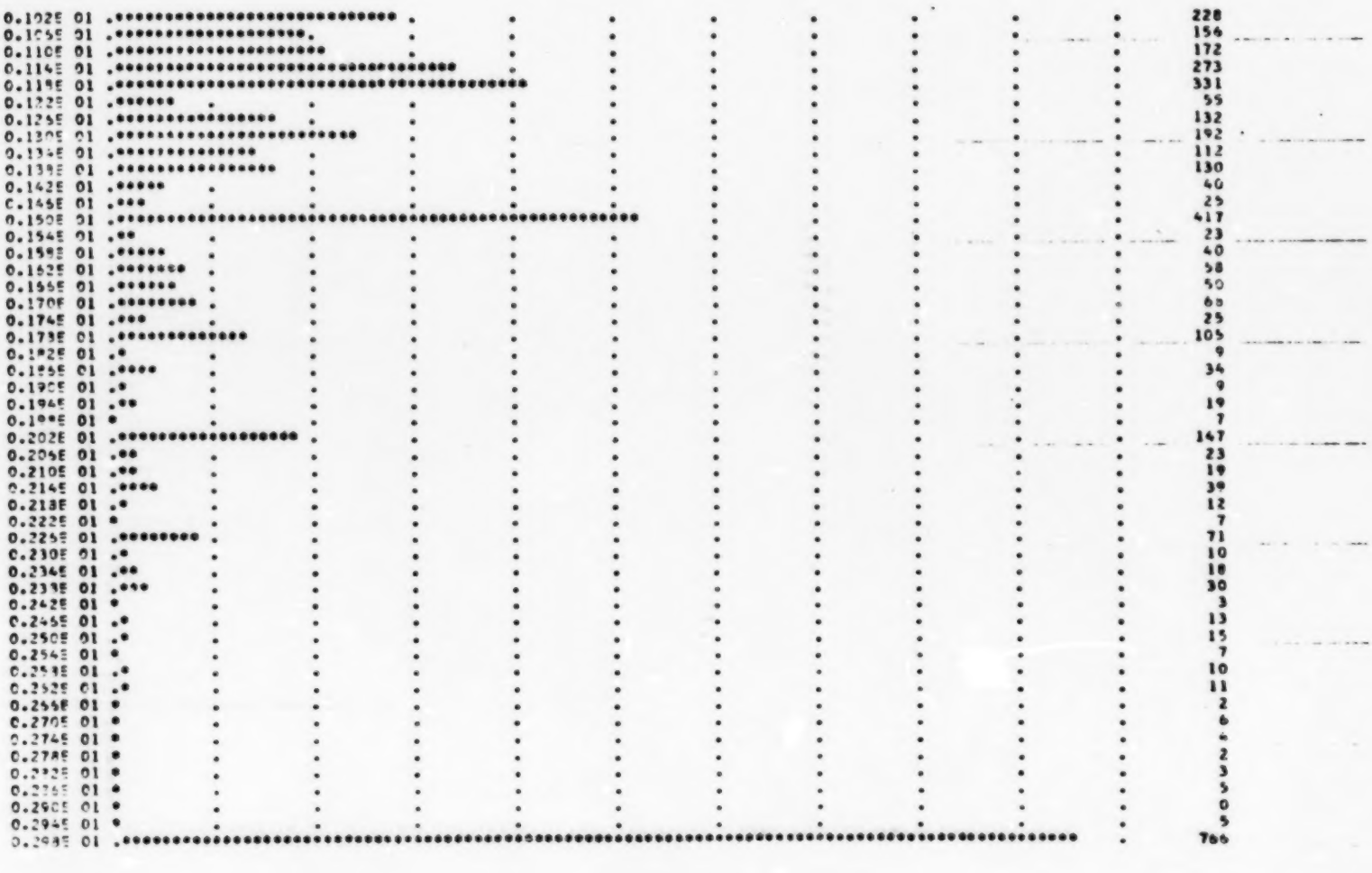
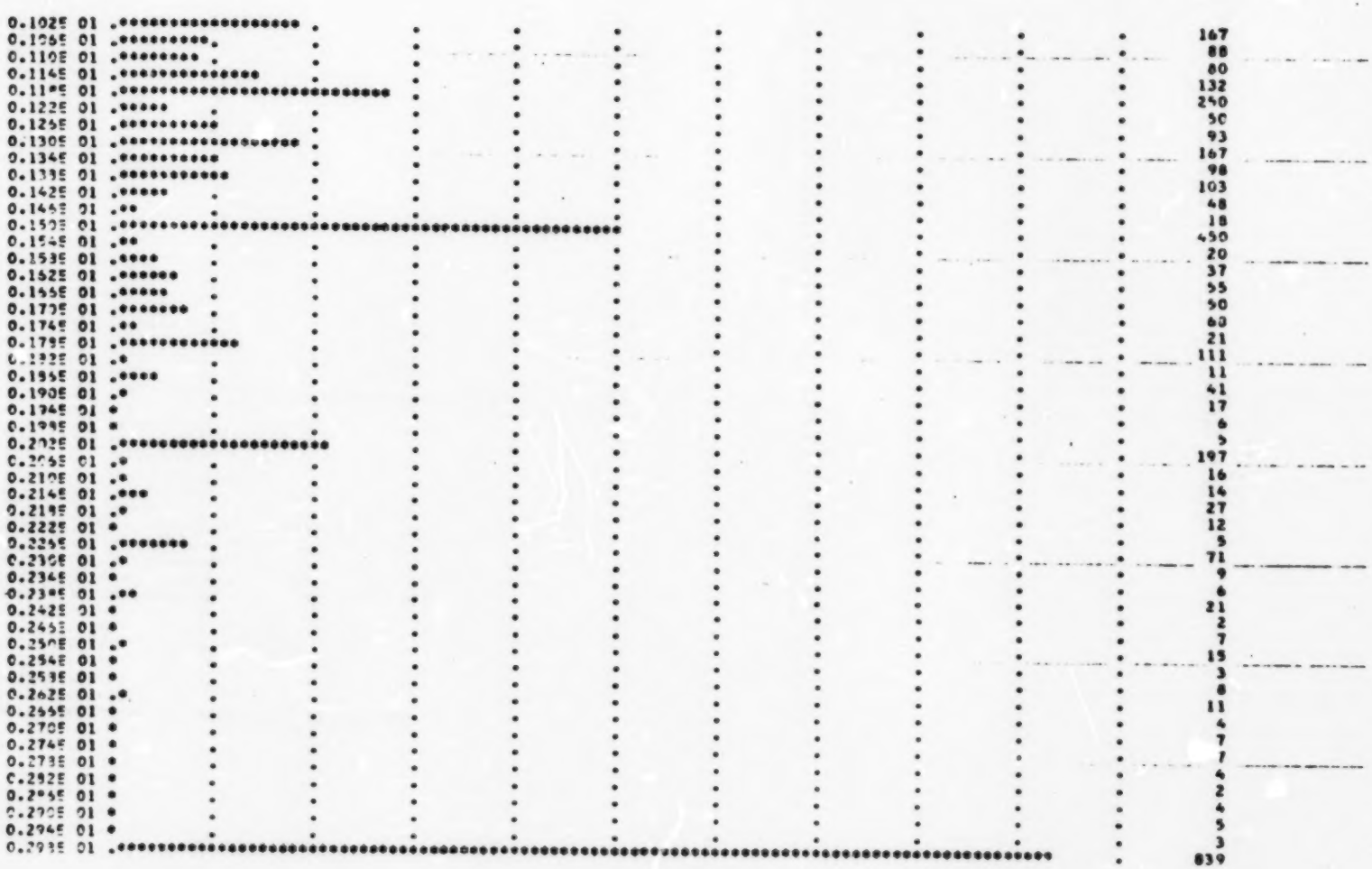
1 TO 3HR RATIOS
SEASON=AUTUMN

Y-SCALE= 0.50E 02



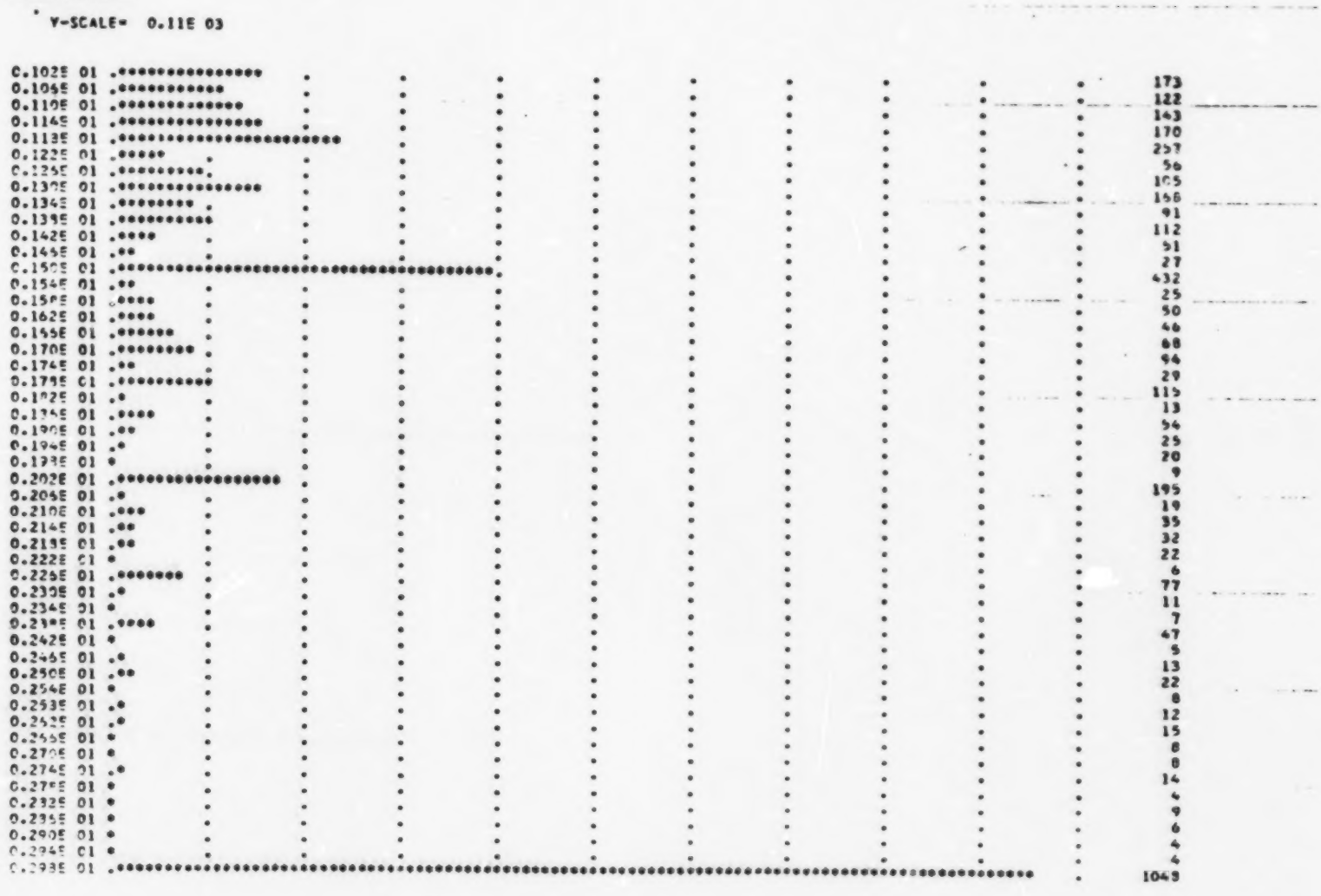
JOINT SEASON-RATIO FREQUENCY DISTRIBUTION
1 TO 3HR RATIOS
SEASON=SUMMER

Y-SCALE= 0.90E 02



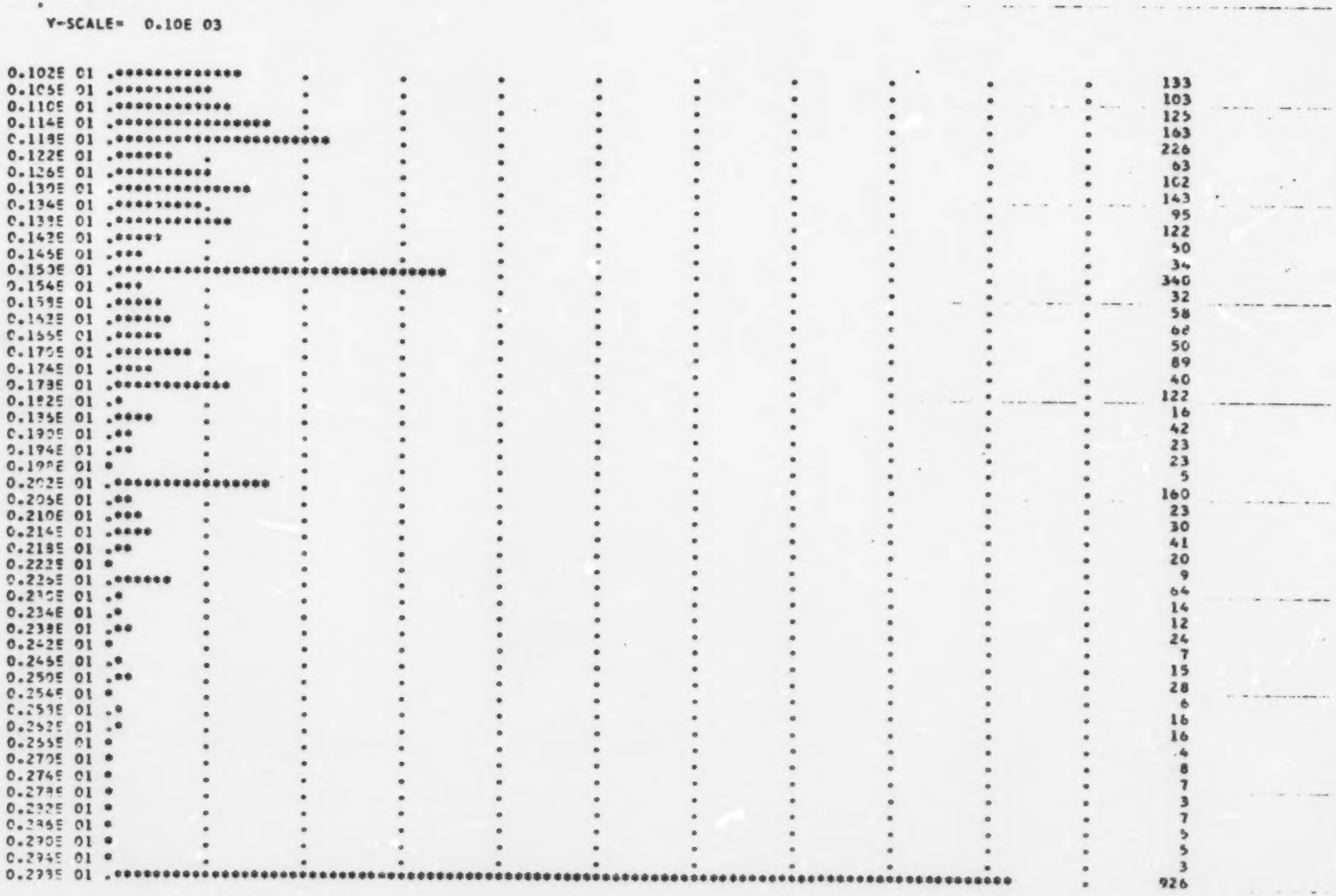
JOINT SEASON-RATIO FREQUENCY DISTRIBUTION
1 TO 3HR RATIOS
SEASON=SPRING

Y-SCALE= 0.11E 03



JOINT SEASON-RATIO FREQUENCY DISTRIBUTION
1 TO 348 RATIOS
SEASON=WINTER

Y-SCALE= 0.10E 03



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1 TO 24HR RATIOS
STABILITY 7

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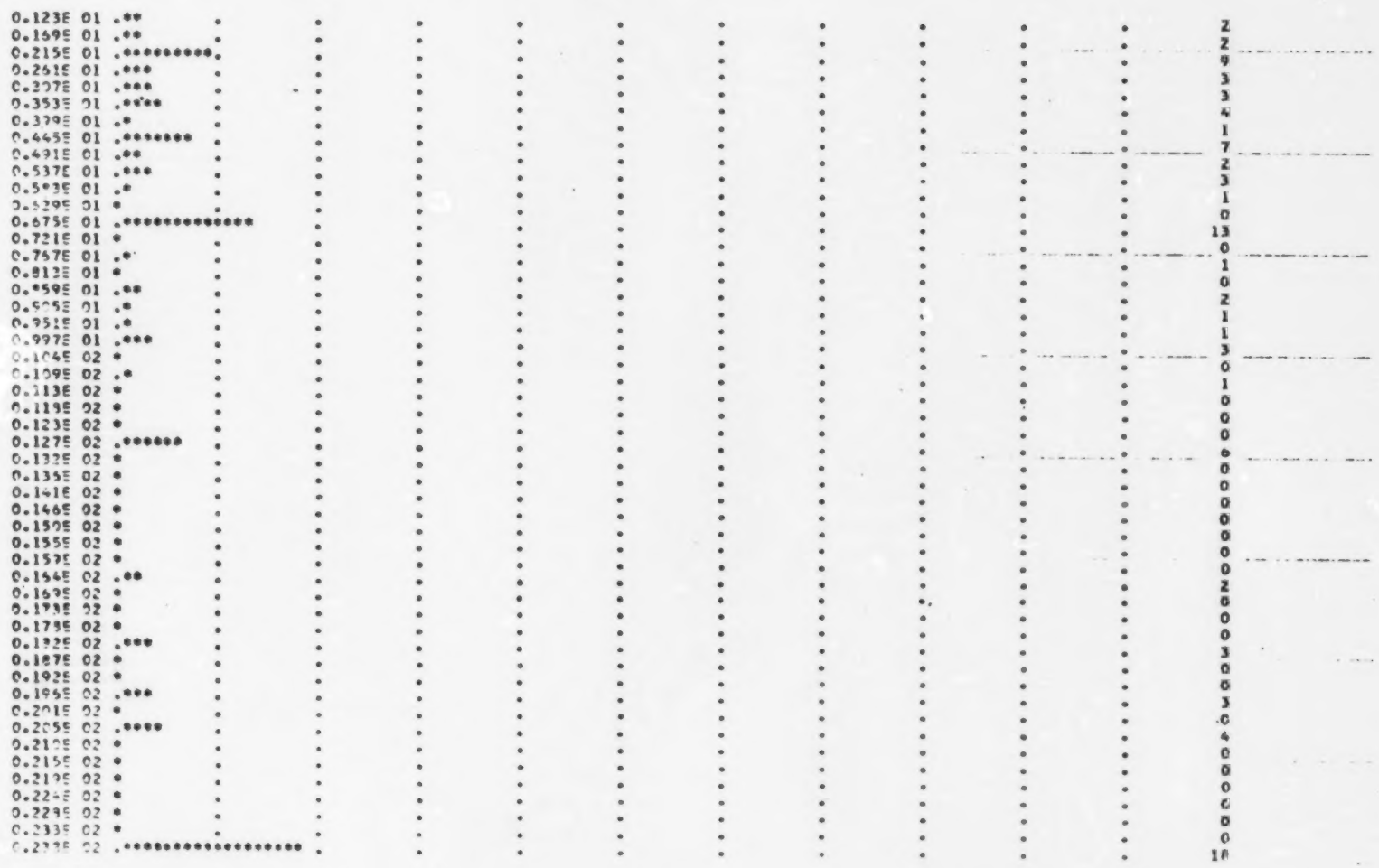

JOINT STABILITY-RATIO FREQUENCY DISTRIBUTION
1 TO 24HR RATIOS
STABILITY 6

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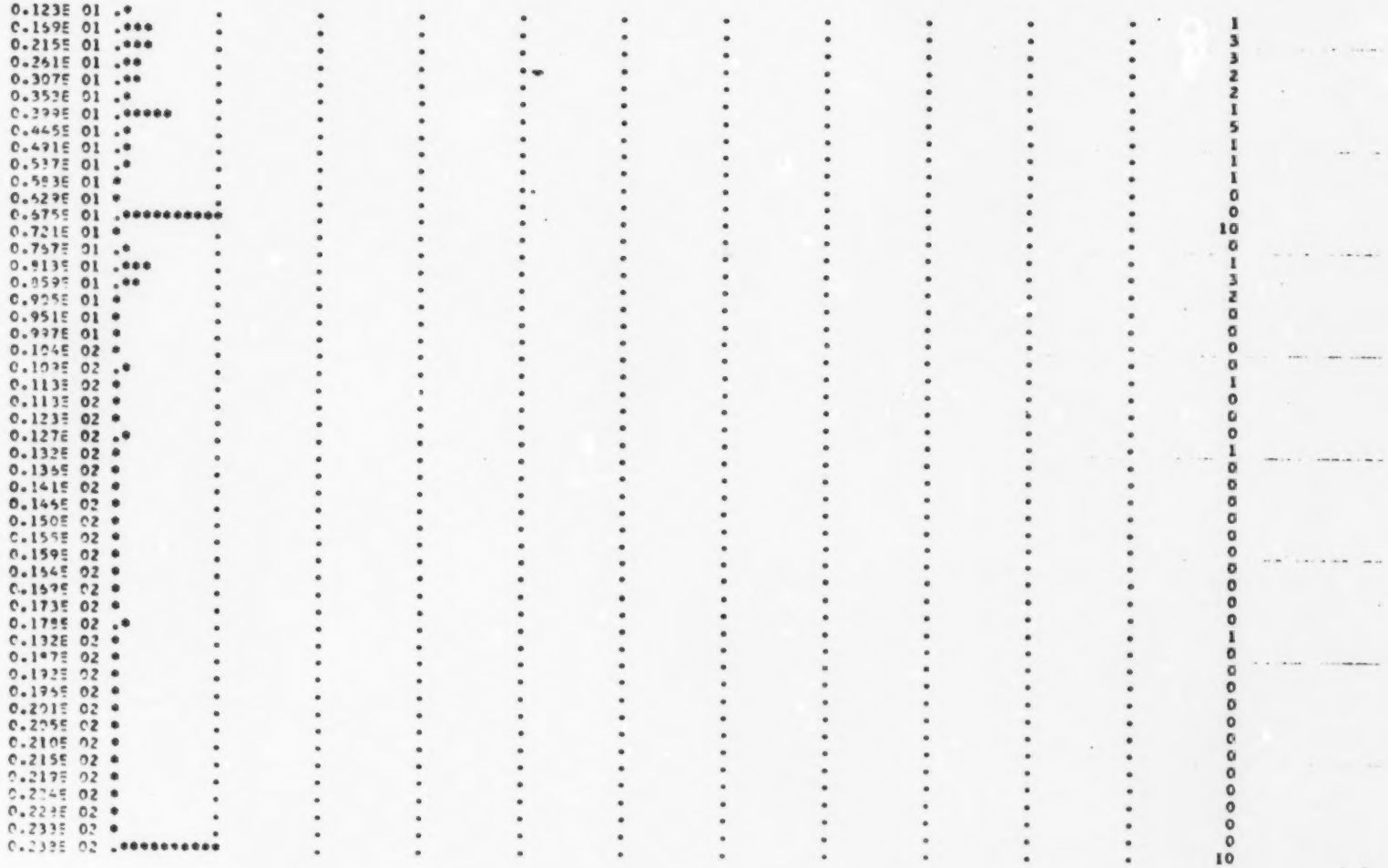
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0.629E 01 *
0.675E 01 .**********
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0.905E 01 *
0.951E 01 *
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JOINT STABILITY-RATIO FREQUENCY DISTRIBUTION
1 TO 24HR RATIOS
STABILITY 5

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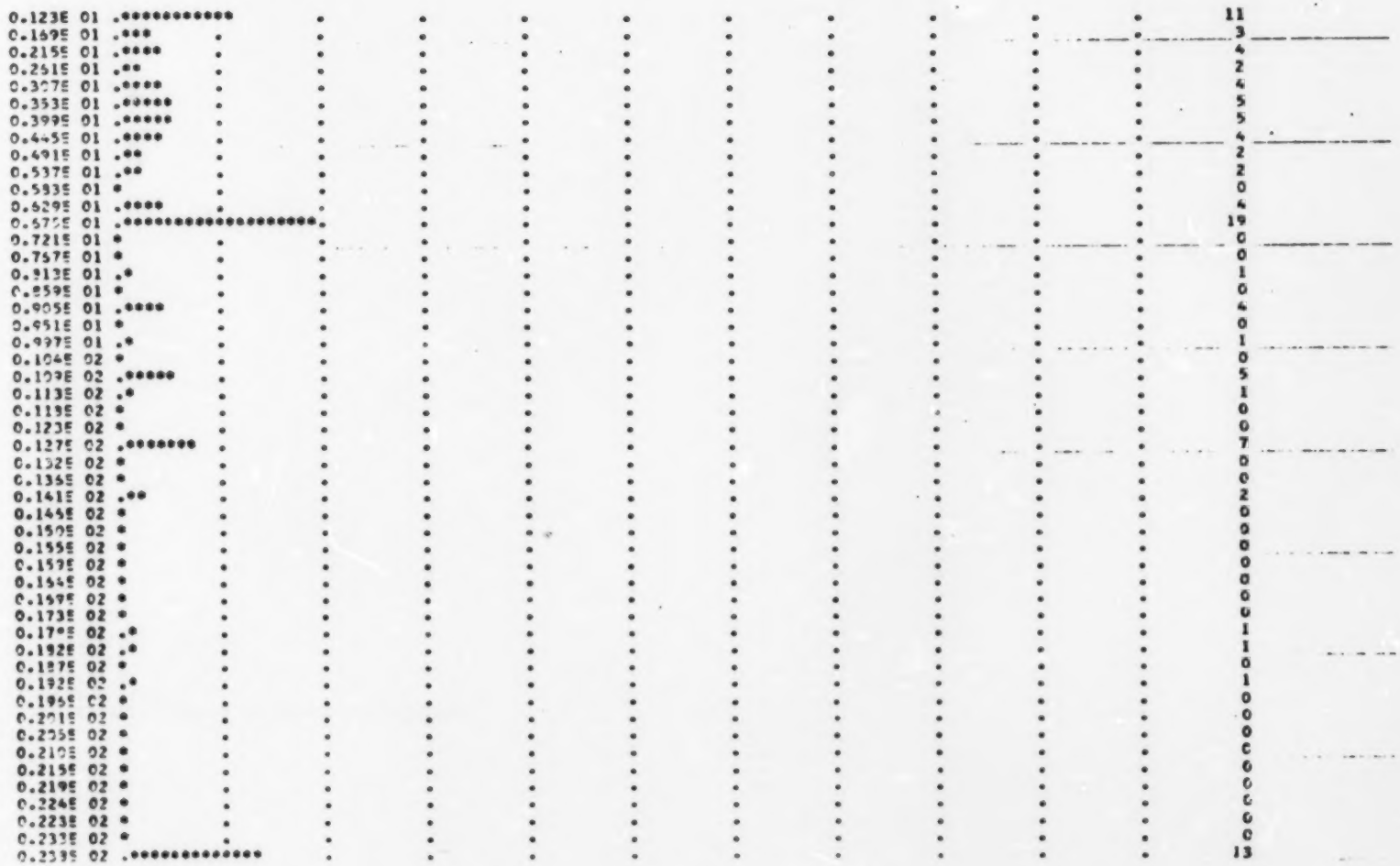

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1 TO 24HR RATIOS
STABILITY 4

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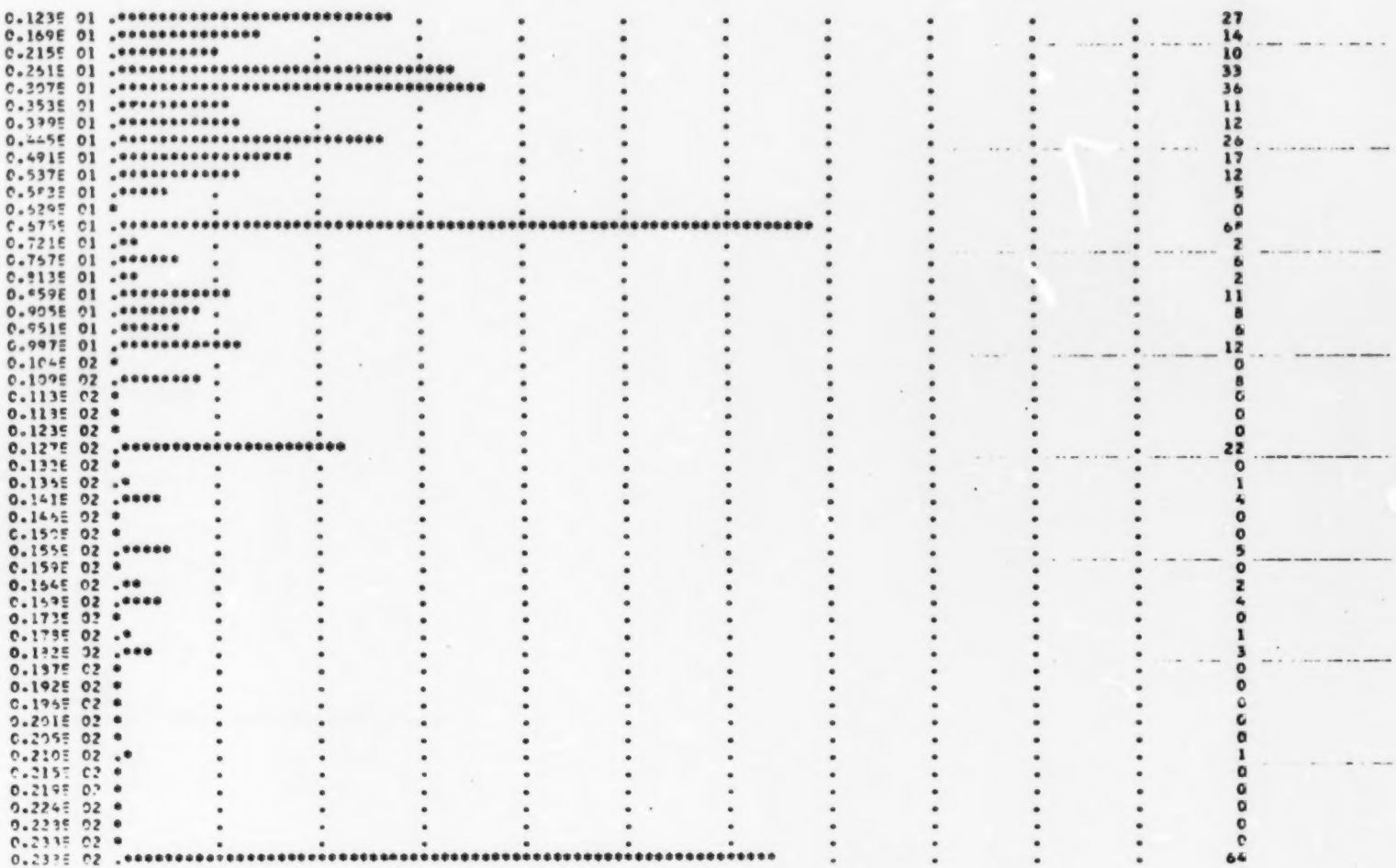

JOINT STABILITY-RATIO FREQUENCY DISTRIBUTION
1 TO 24HR RATIOS
STABILITY 3

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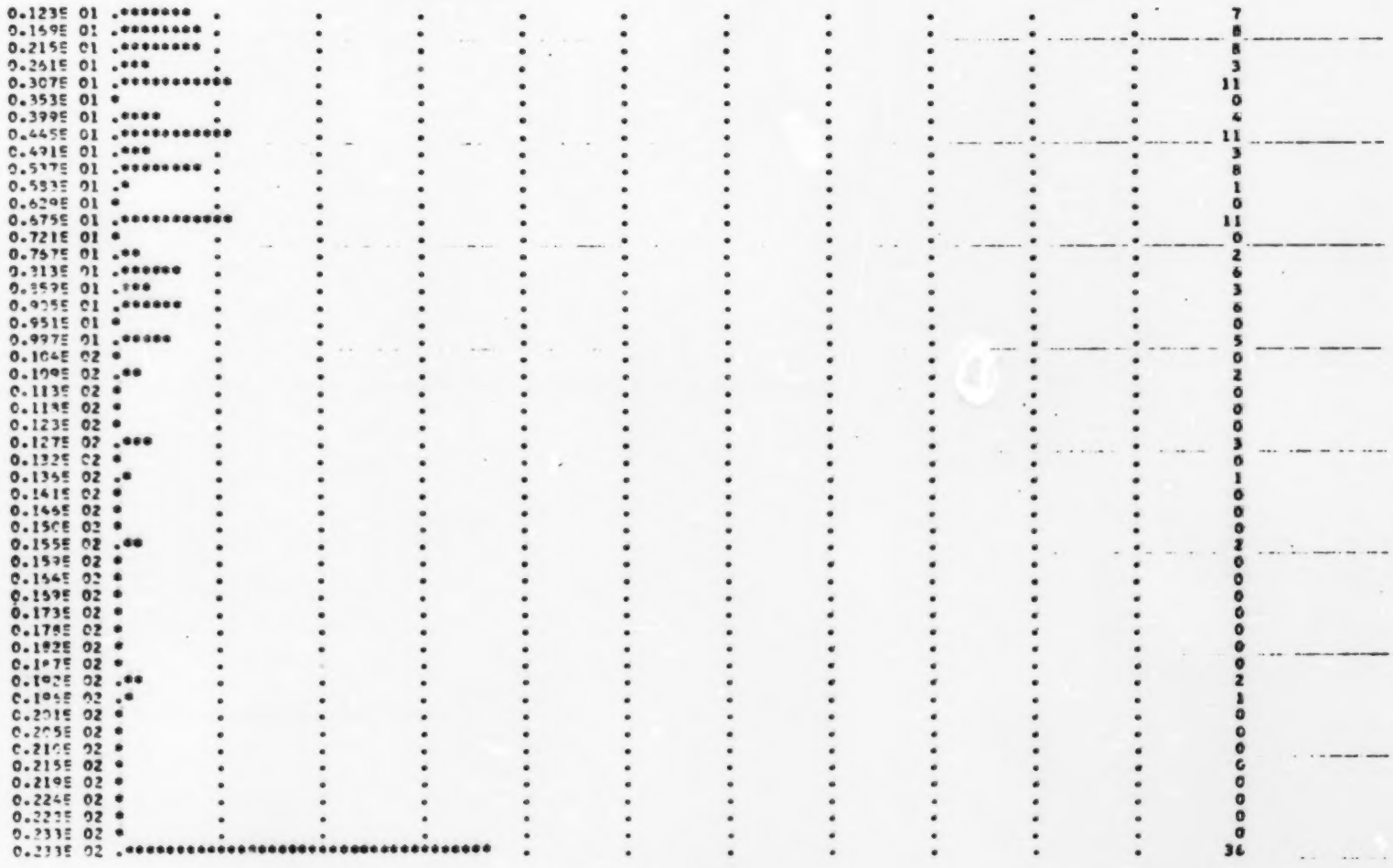

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1 TO 24HR RATIOS
STABILITY 2

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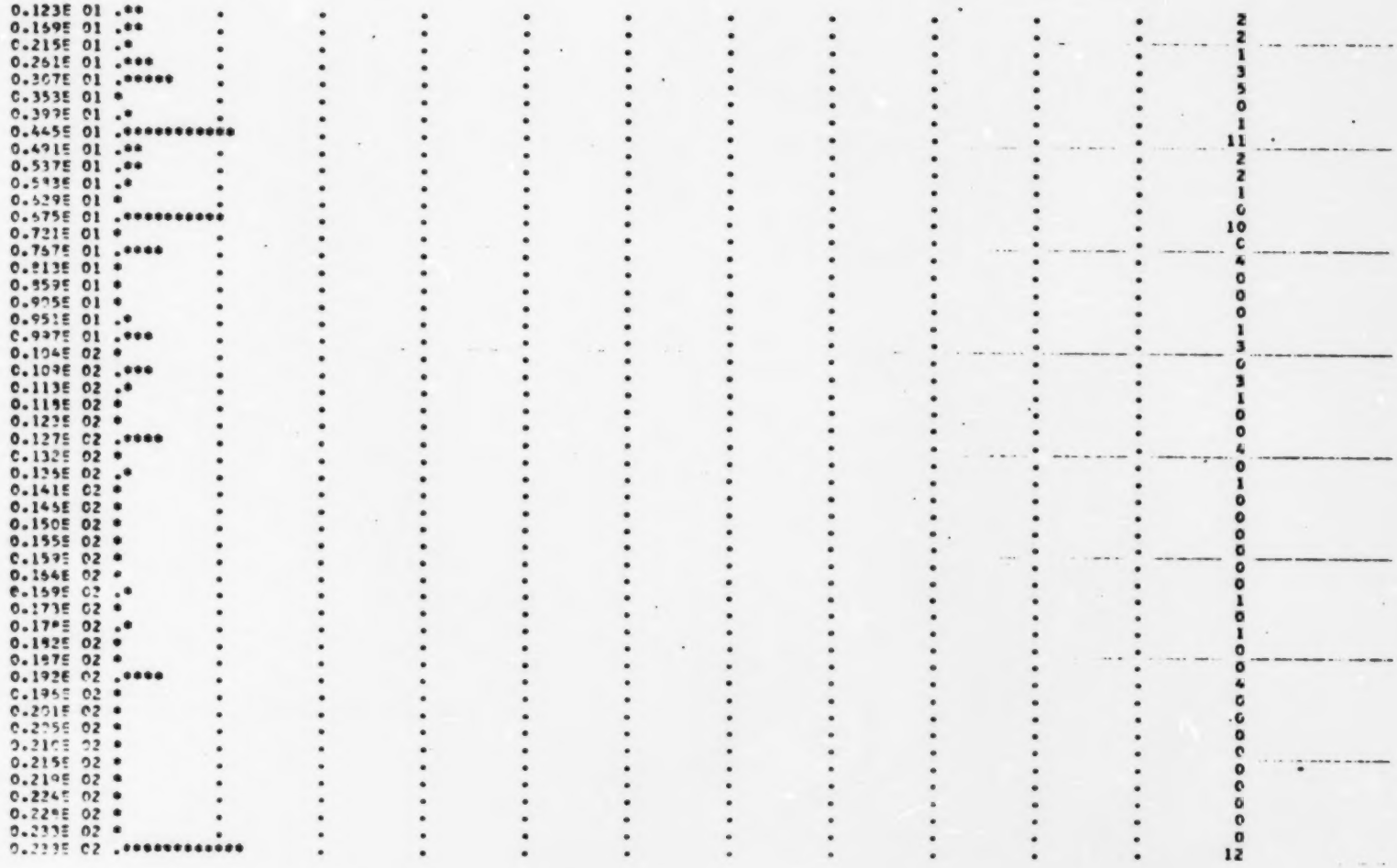

JOINT STABILITY-RATIO FREQUENCY DISTRIBUTION
1 TO 24HR RATIOS
STABILITY 1

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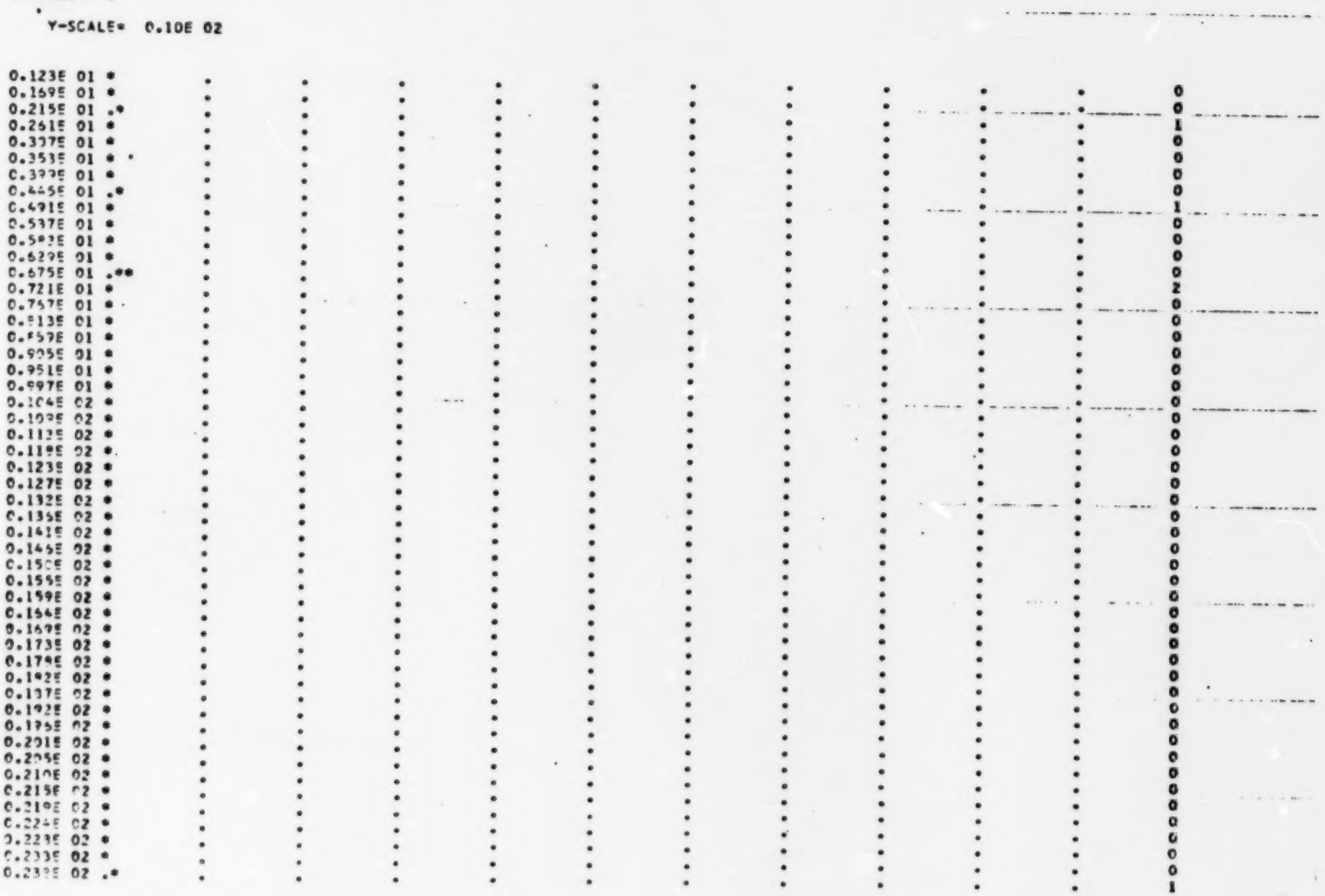

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1 TO 3HR RATIOS
STABILITY 7

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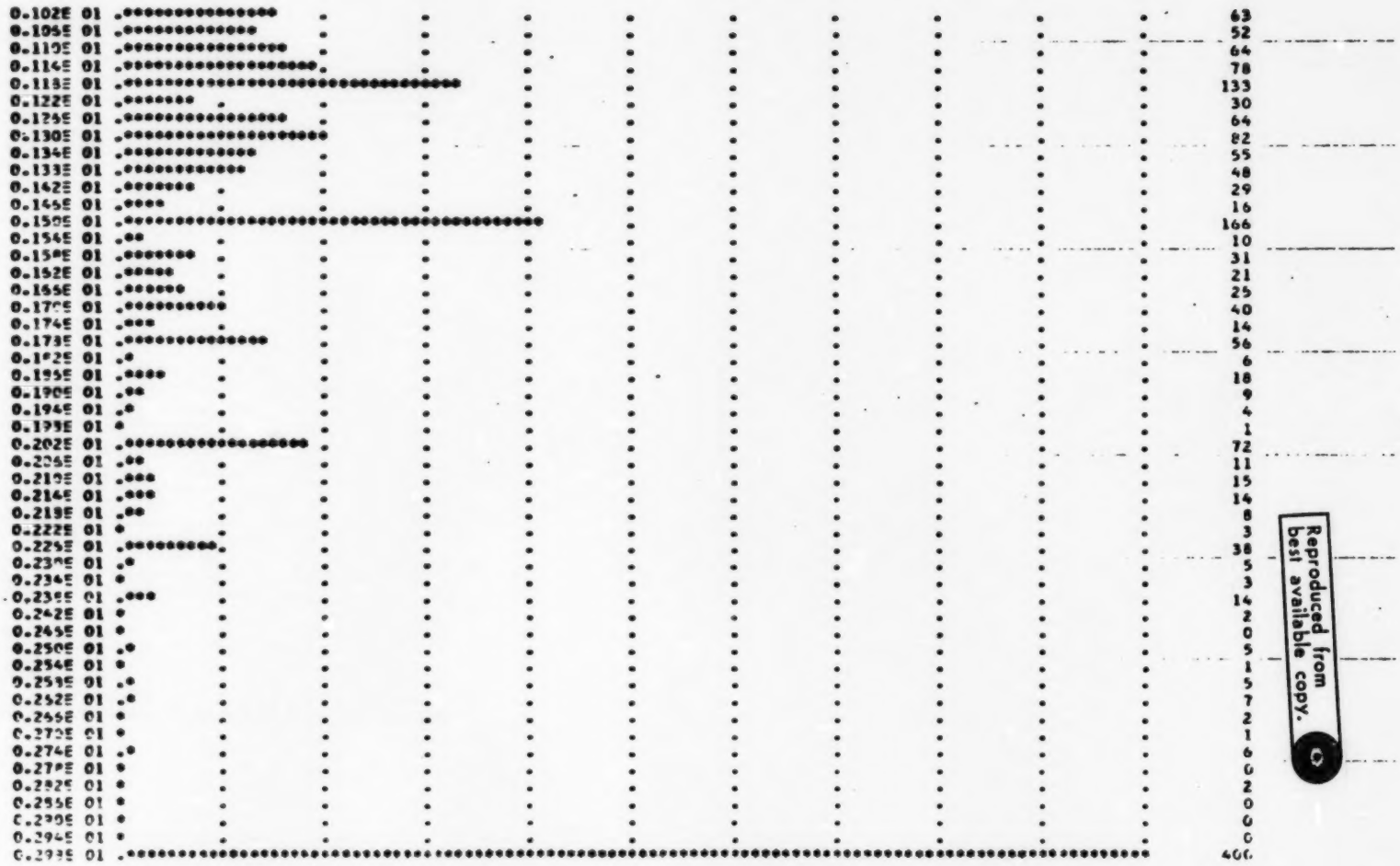

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JOINT STABILITY-RATIO FREQUENCY DISTRIBUTION
1 TO 3HR RATIOS
STABILITY 6

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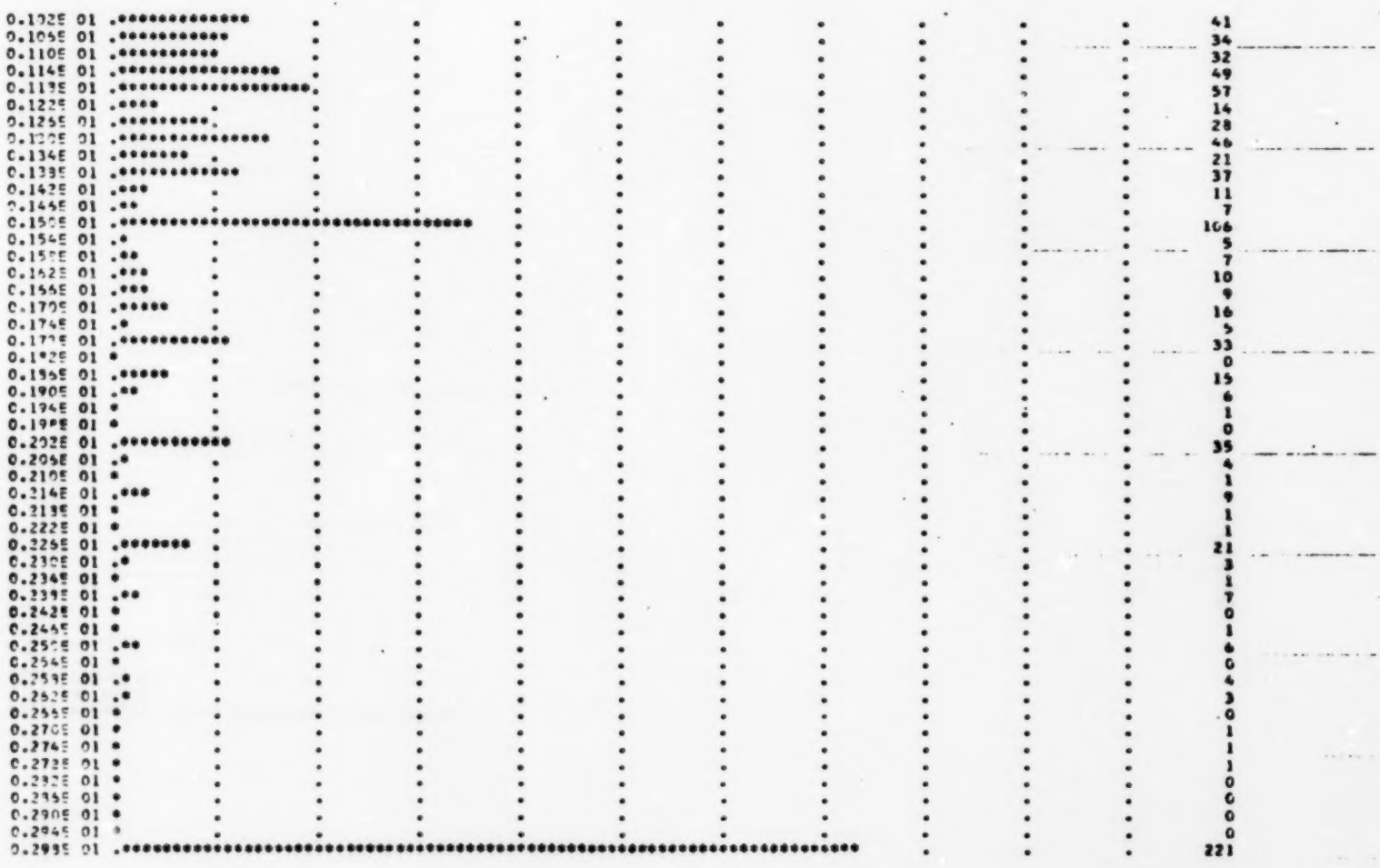

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1 TO 3HR RATIOS
STABILITY 5

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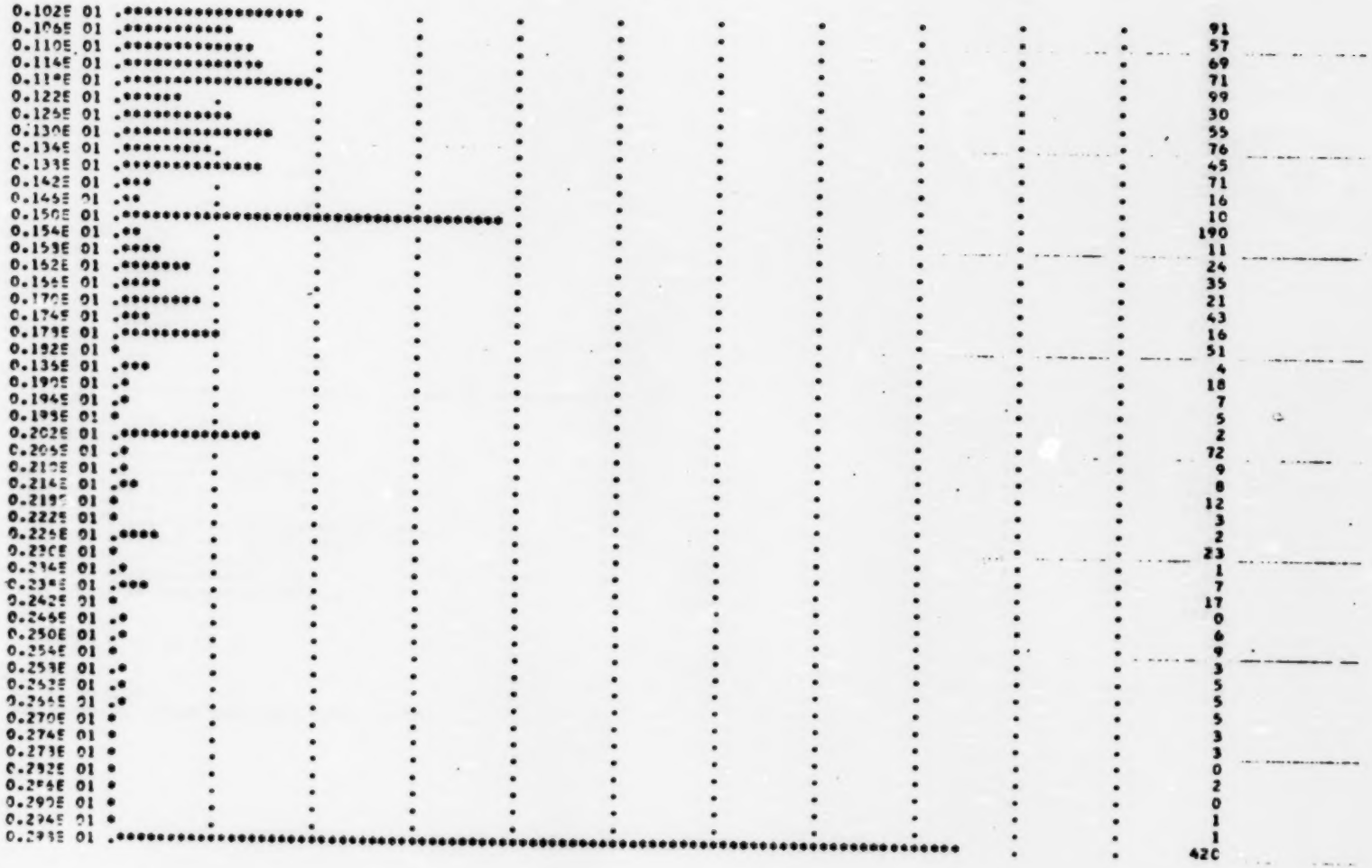

JOINT STABILITY-RATIO FREQUENCY DISTRIBUTION
1 TO 3HR RATIOS
STABILITY 4

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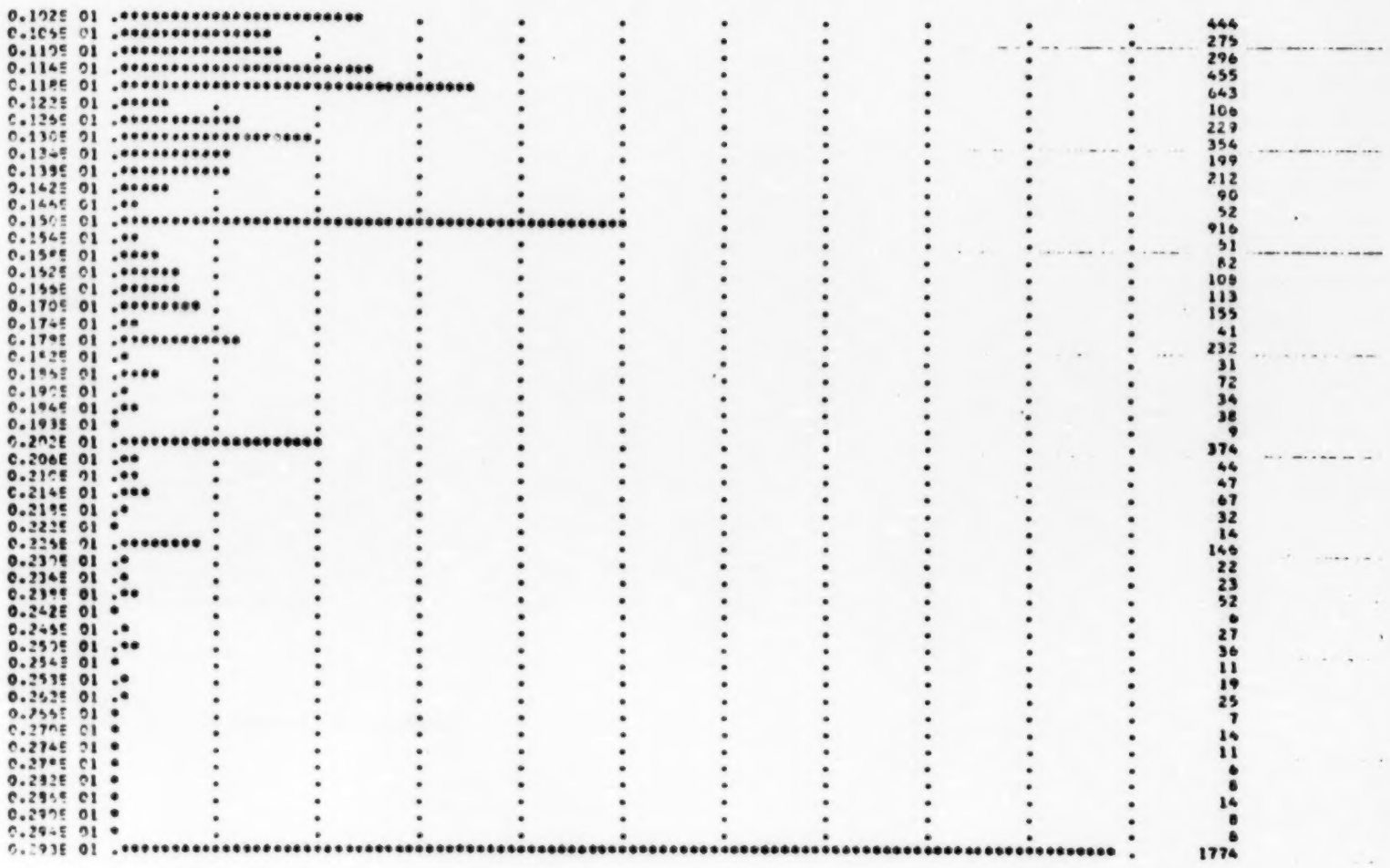

JOINT STABILITY-RATIO FREQUENCY DISTRIBUTION
1 TO 3HR RATIOS
STABILITY 3

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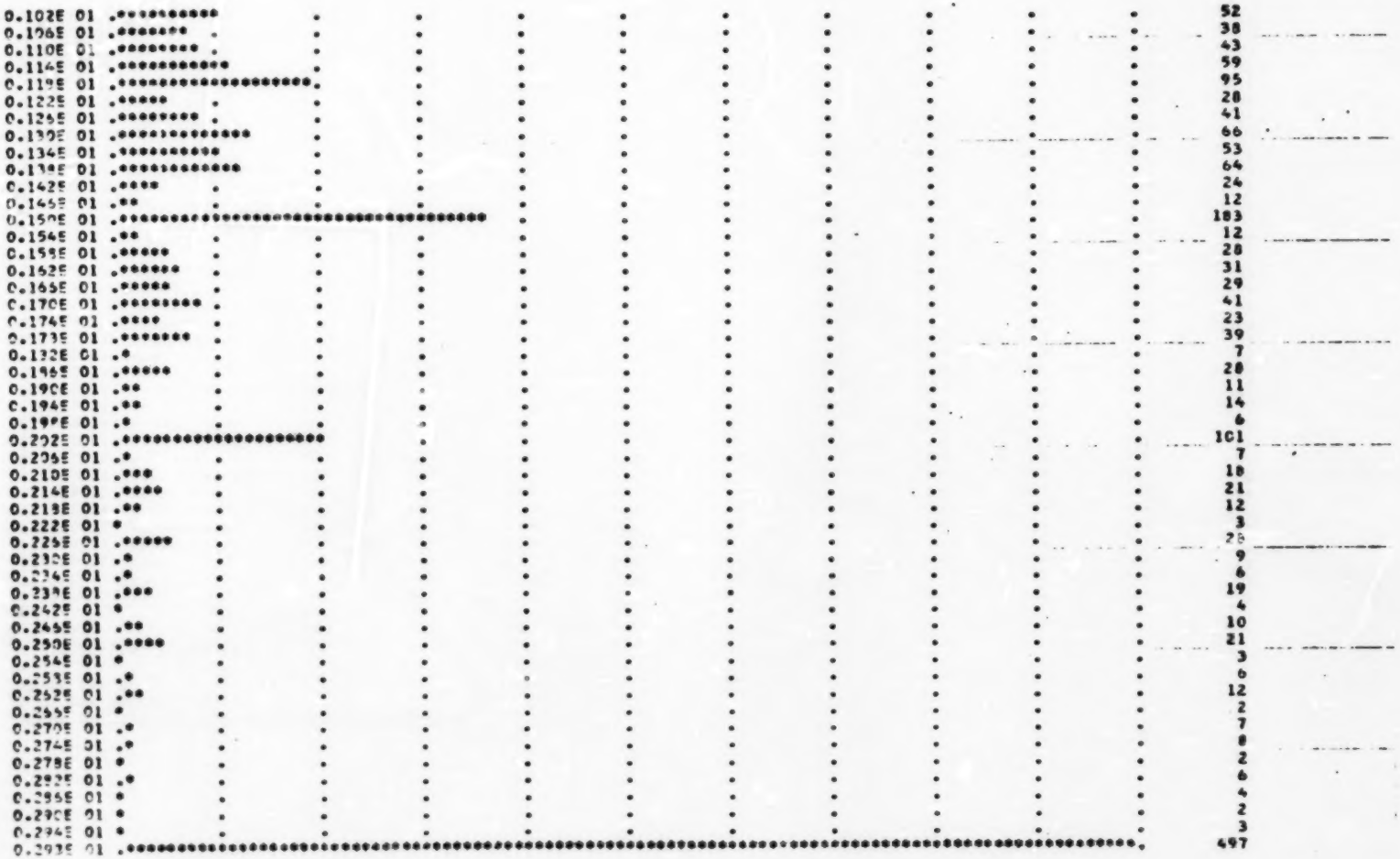

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1 TO 3HR RATIOS
STABILITY 2

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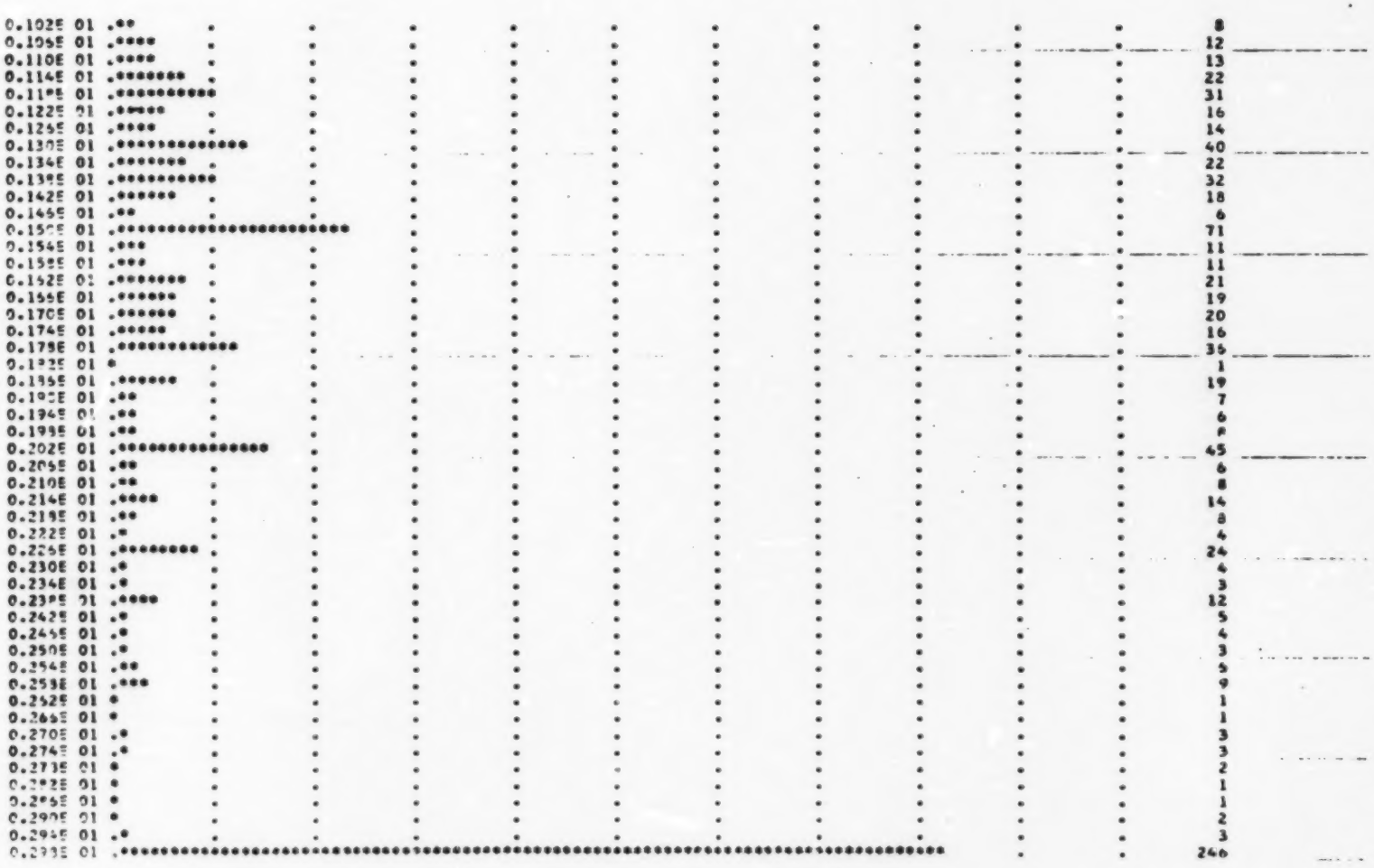

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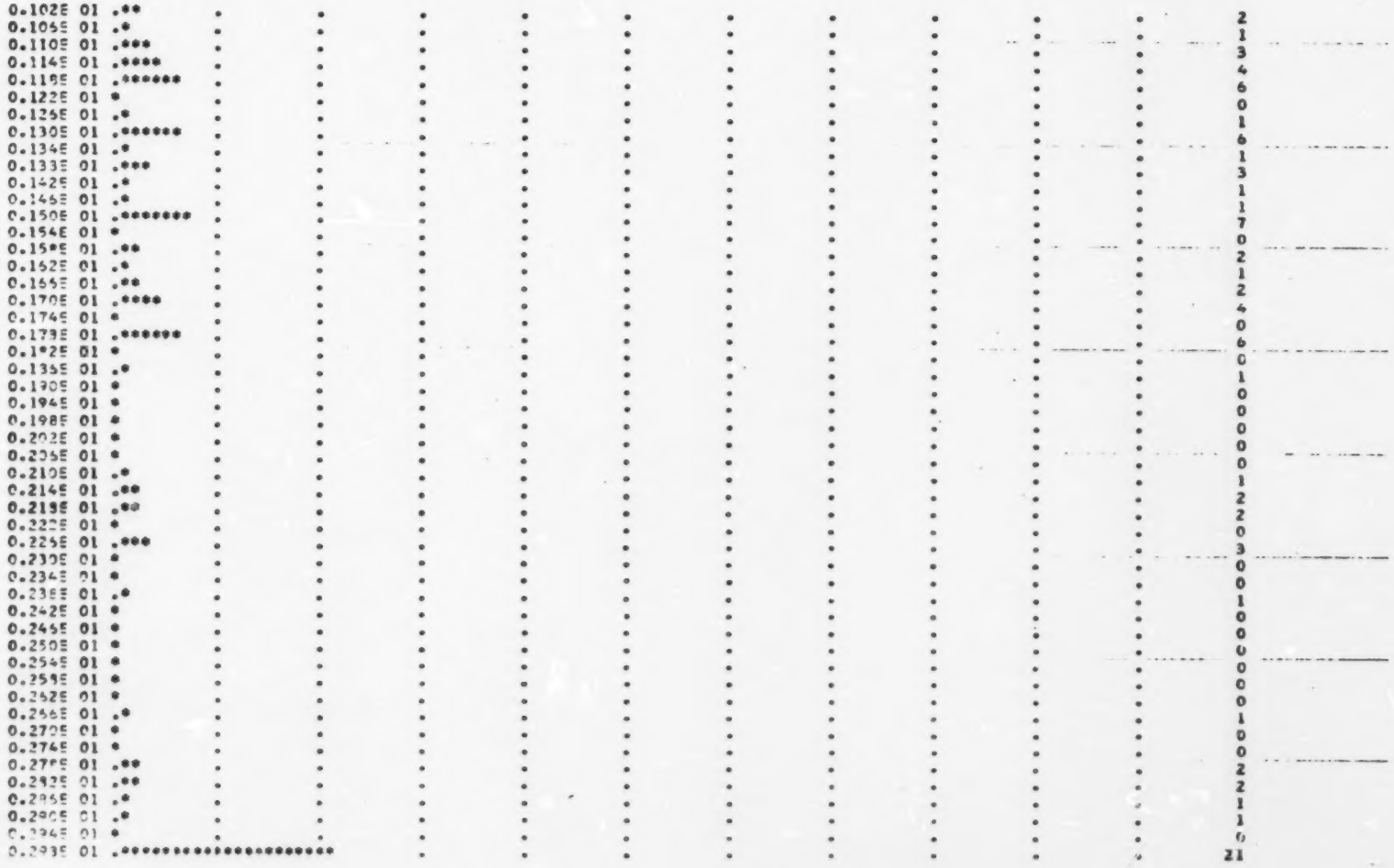

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1 TO 24HR RATIOS
RECEPTOR 4

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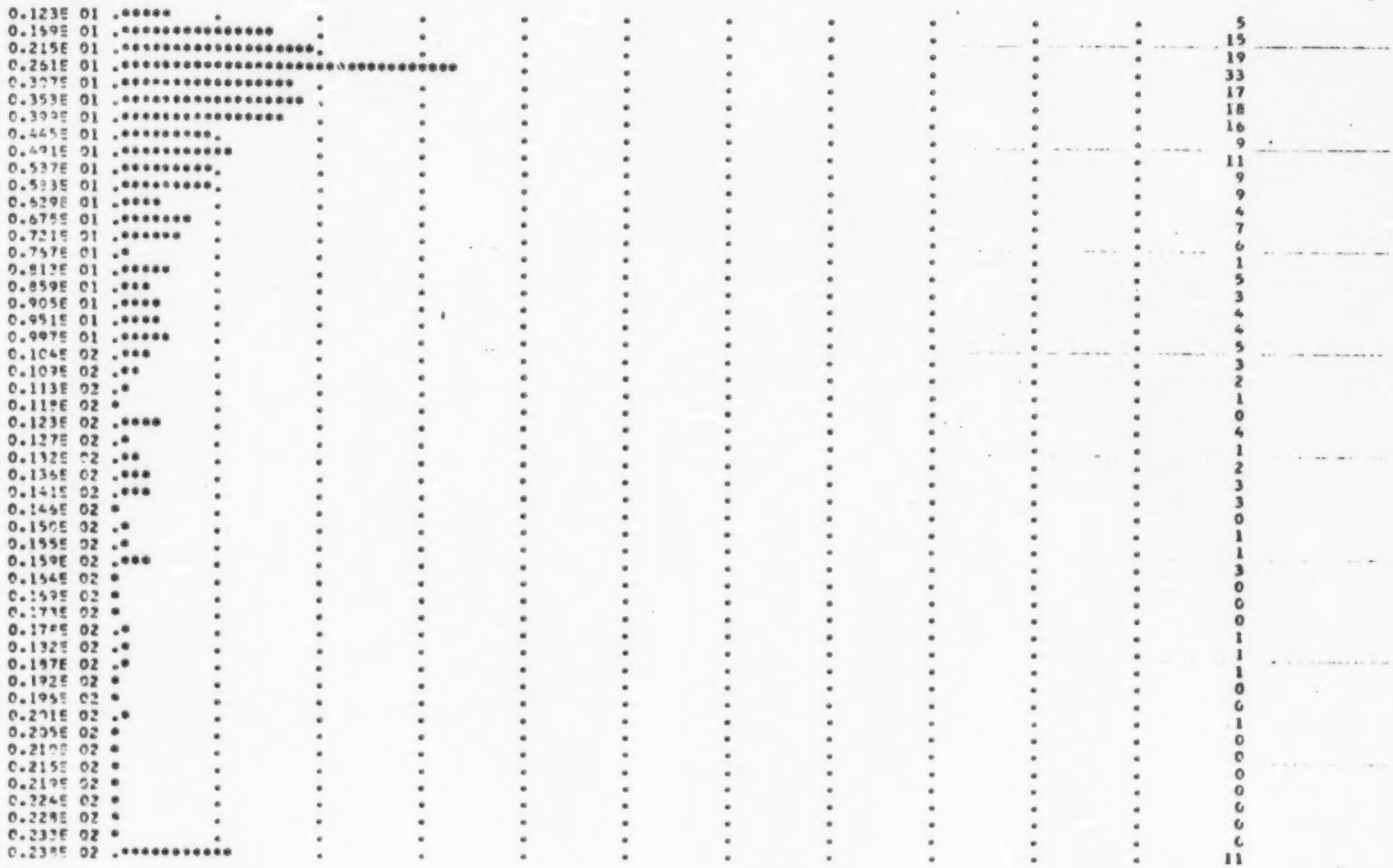

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1 TO 24HR RATIOS
RECEPTOR 3

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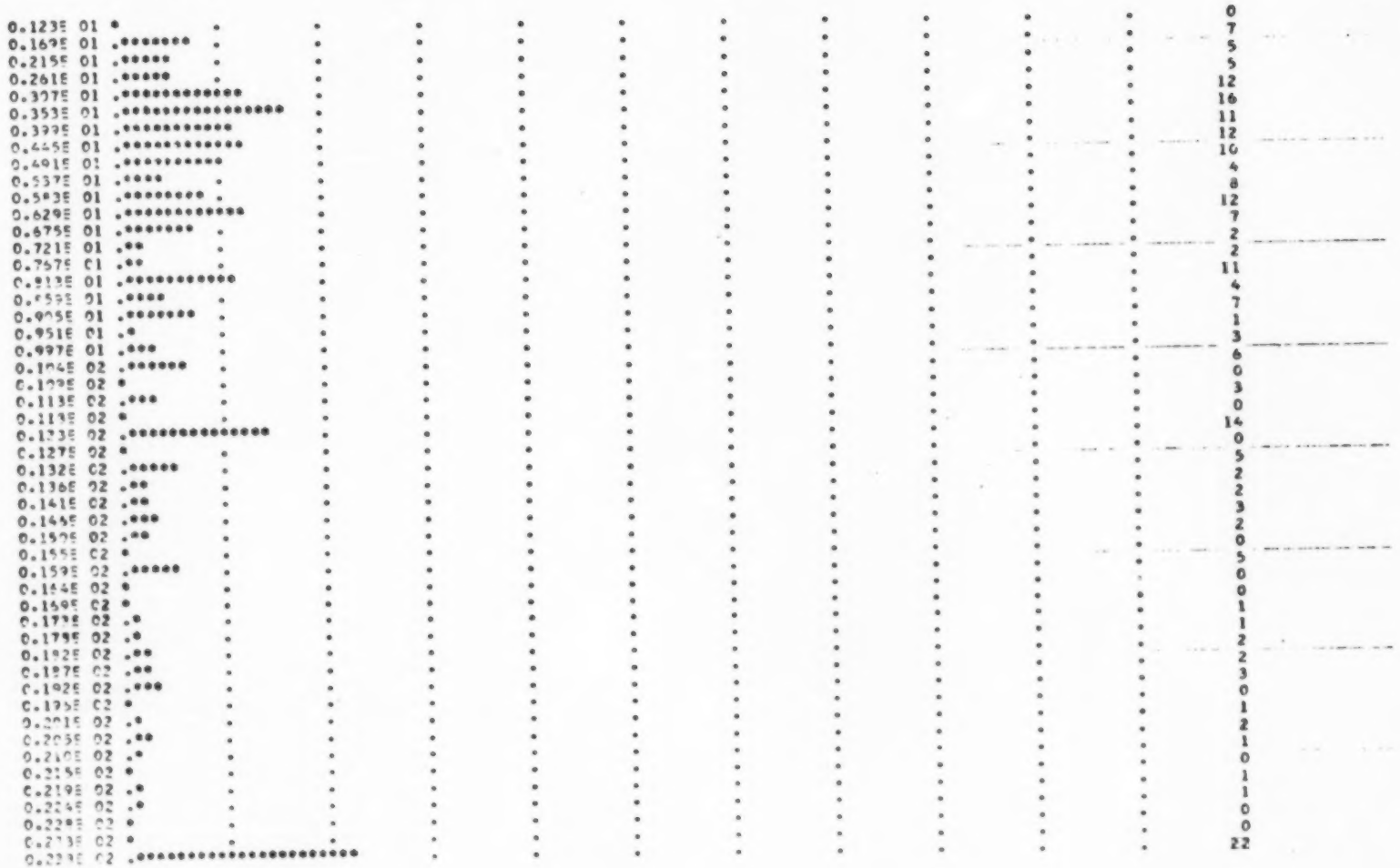

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1 TO 24HR RATIOS
RECEPTOR 2

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1 TO 24HR RATIOS
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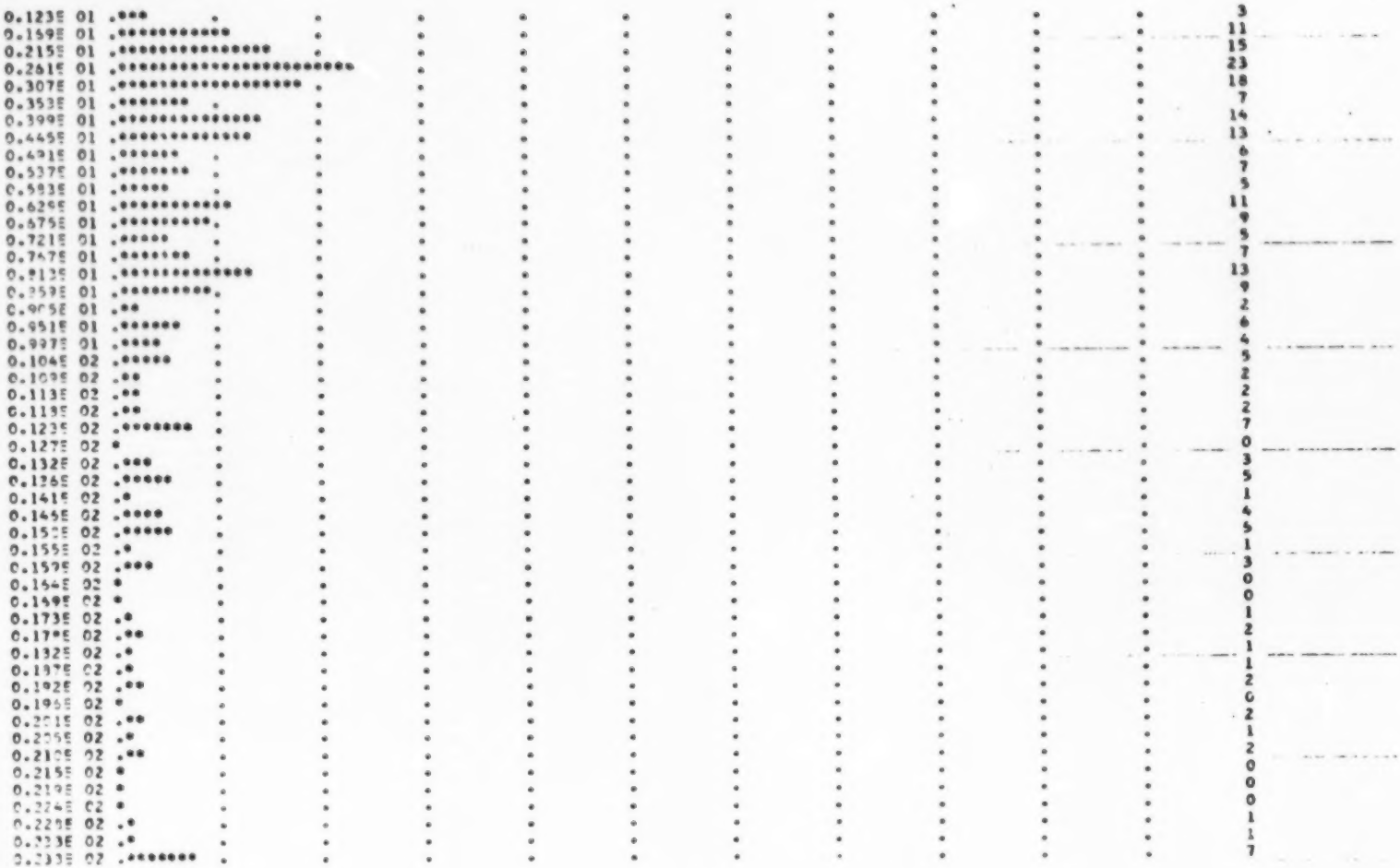

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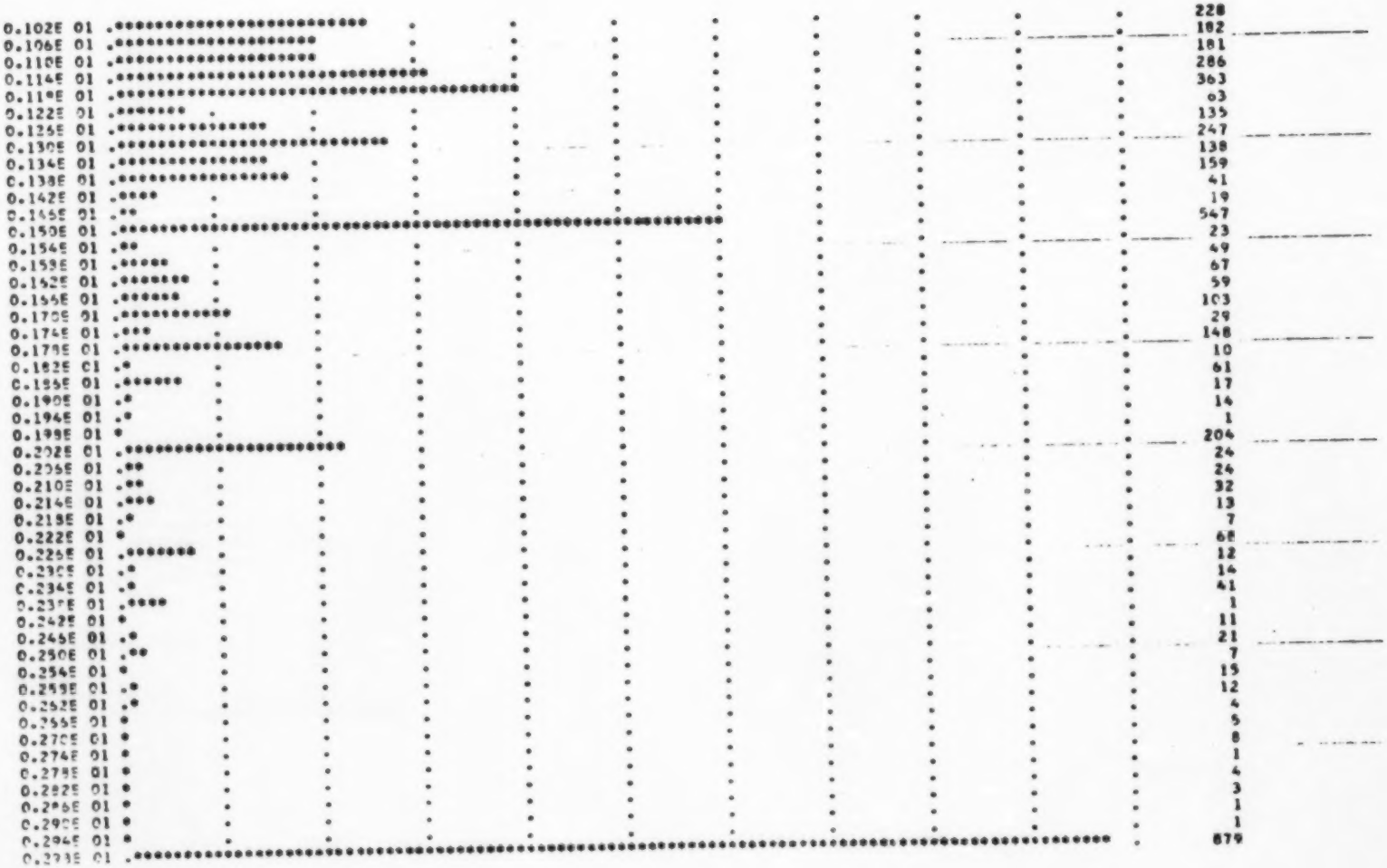

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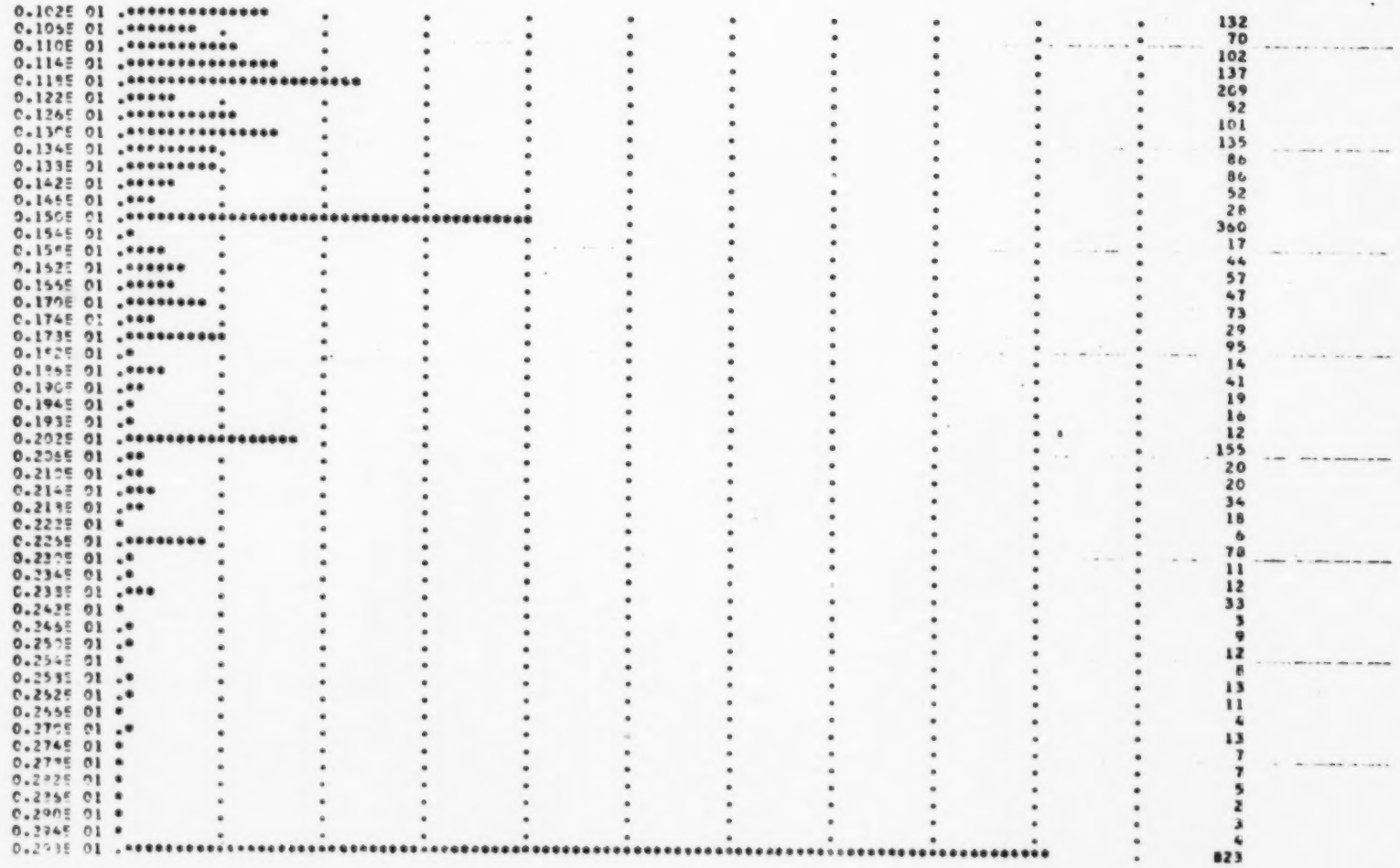

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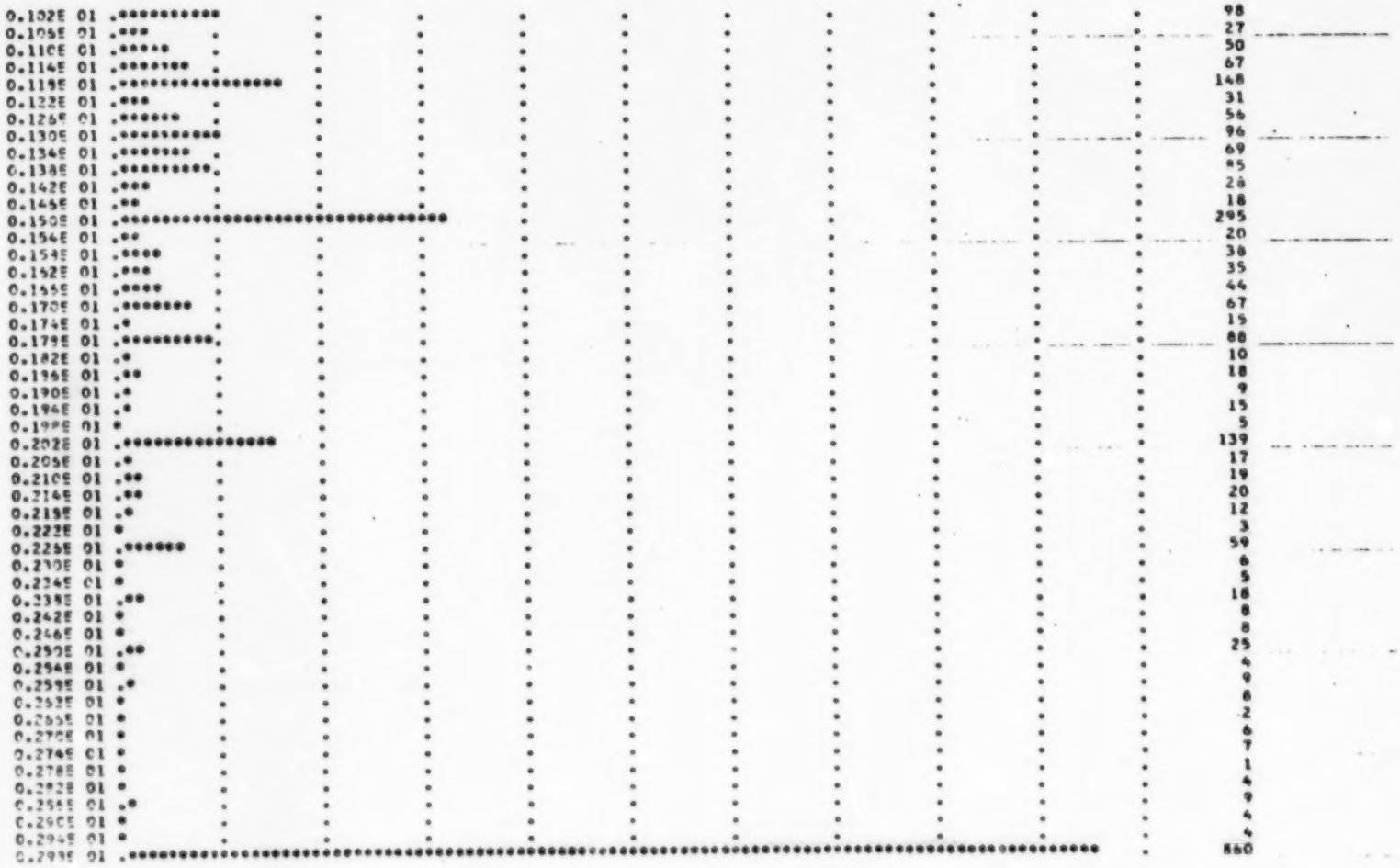

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1 TO 3HR RATIOS
RECEPTOR 1

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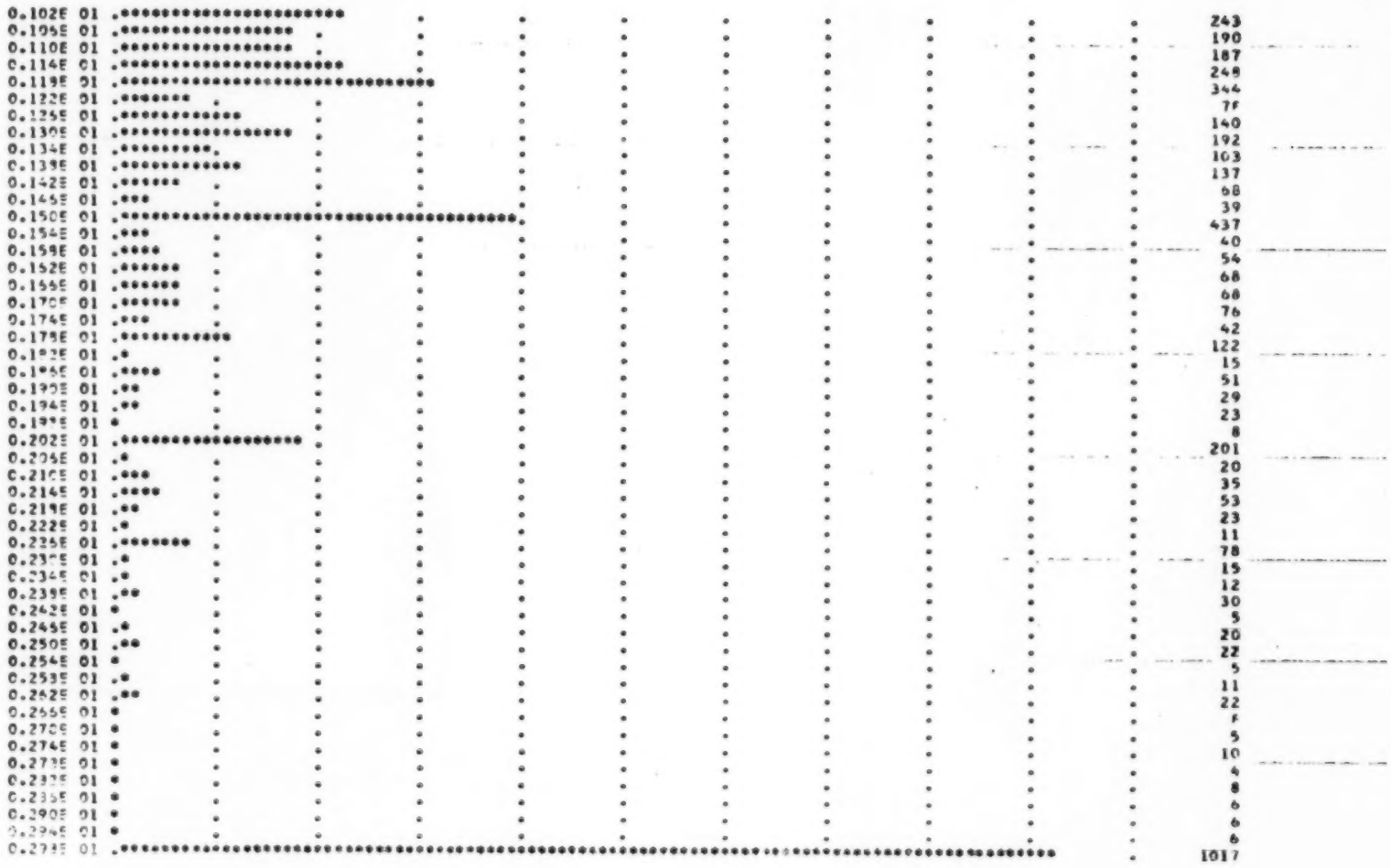

JOINT WINDSPEED RATIO FREQUENCY DISTRIBUTION
1 TO 24HR RATIOS
WINDSPEED CLASS 5

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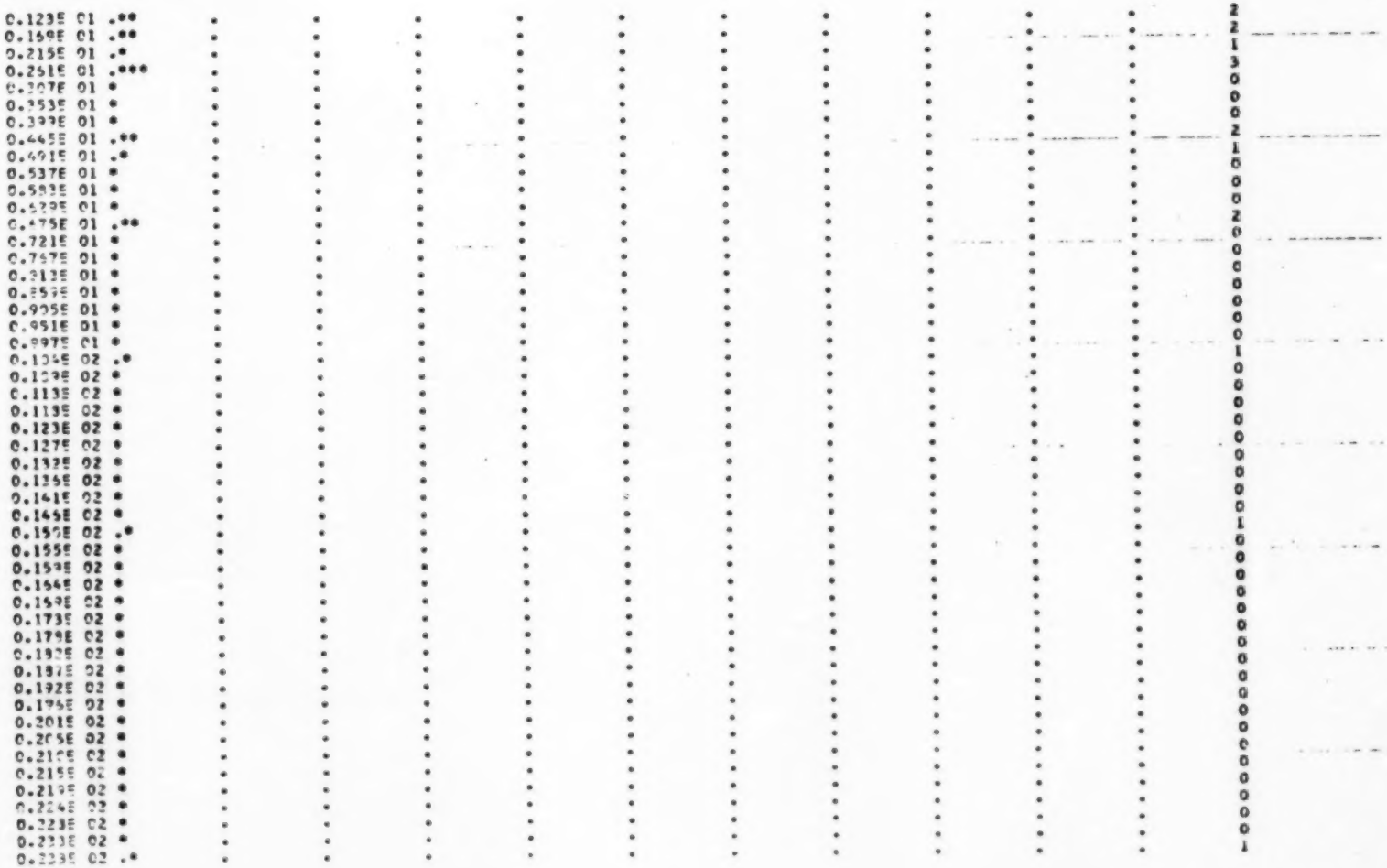
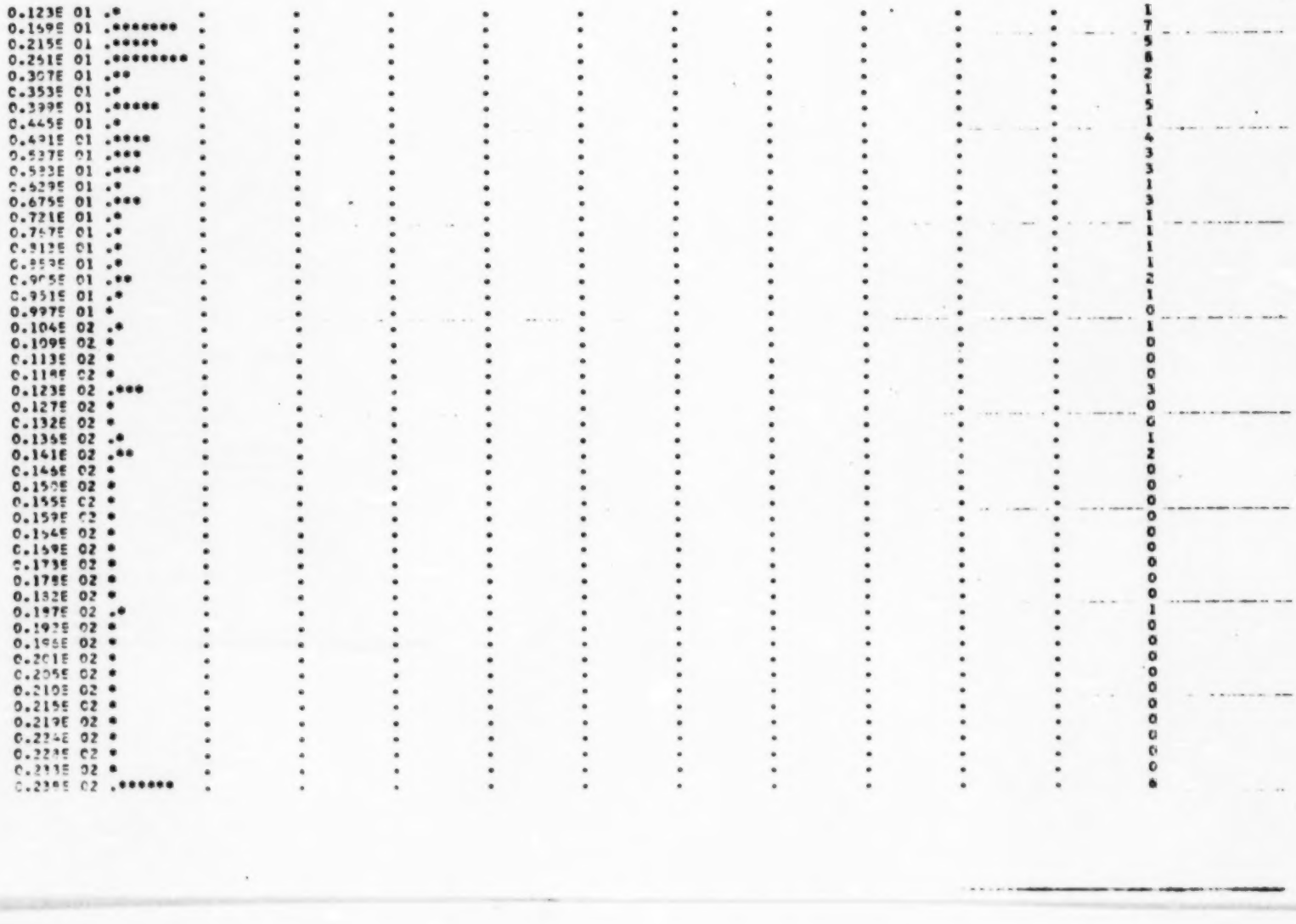


JOINT WINDSPEED RATIO FREQUENCY DISTRIBUTION
1 TO 24HR RATIOS
WINDSPEED CLASS 4

Y-SCALE= 0.10E 02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0.675E 01 .***
0.721E 01 .*
0.767E 01 .*
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0.859E 01 .*
0.905E 01 .**
0.951E 01 .*
0.997E 01 *
0.104E 02 .*
0.109E 02 *
0.113E 02 *
0.118E 02 *
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0.238E 02 .******
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JOINT WINDSPEED RATIO FREQUENCY DISTRIBUTION
1 TO 24HR RATIOS
WINDSPEED CLASS 3

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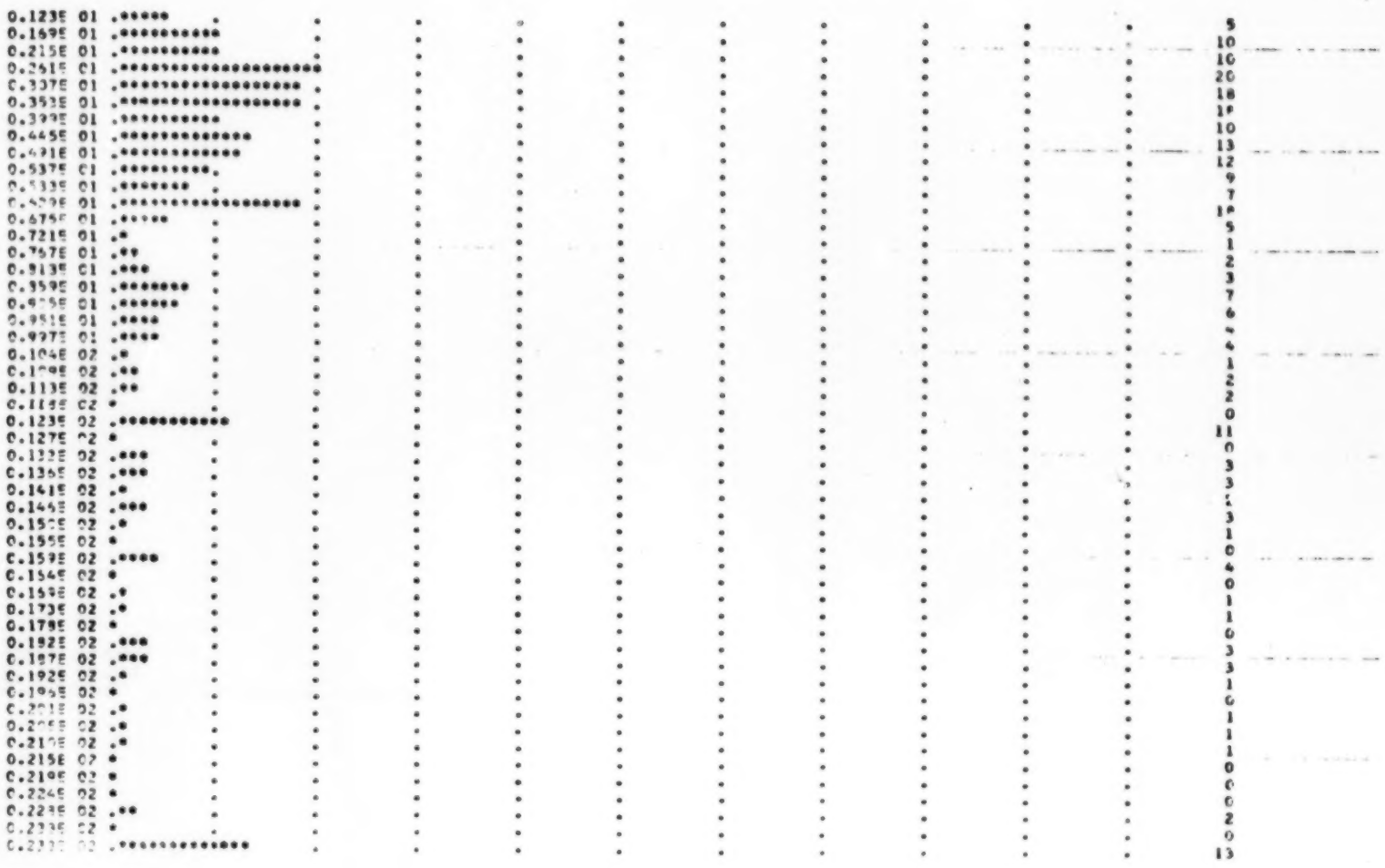

JOINT WINDSPEED RATIO FREQUENCY DISTRIBUTION
1 TO 24HR RATIOS
WINDSPEED CLASS 2

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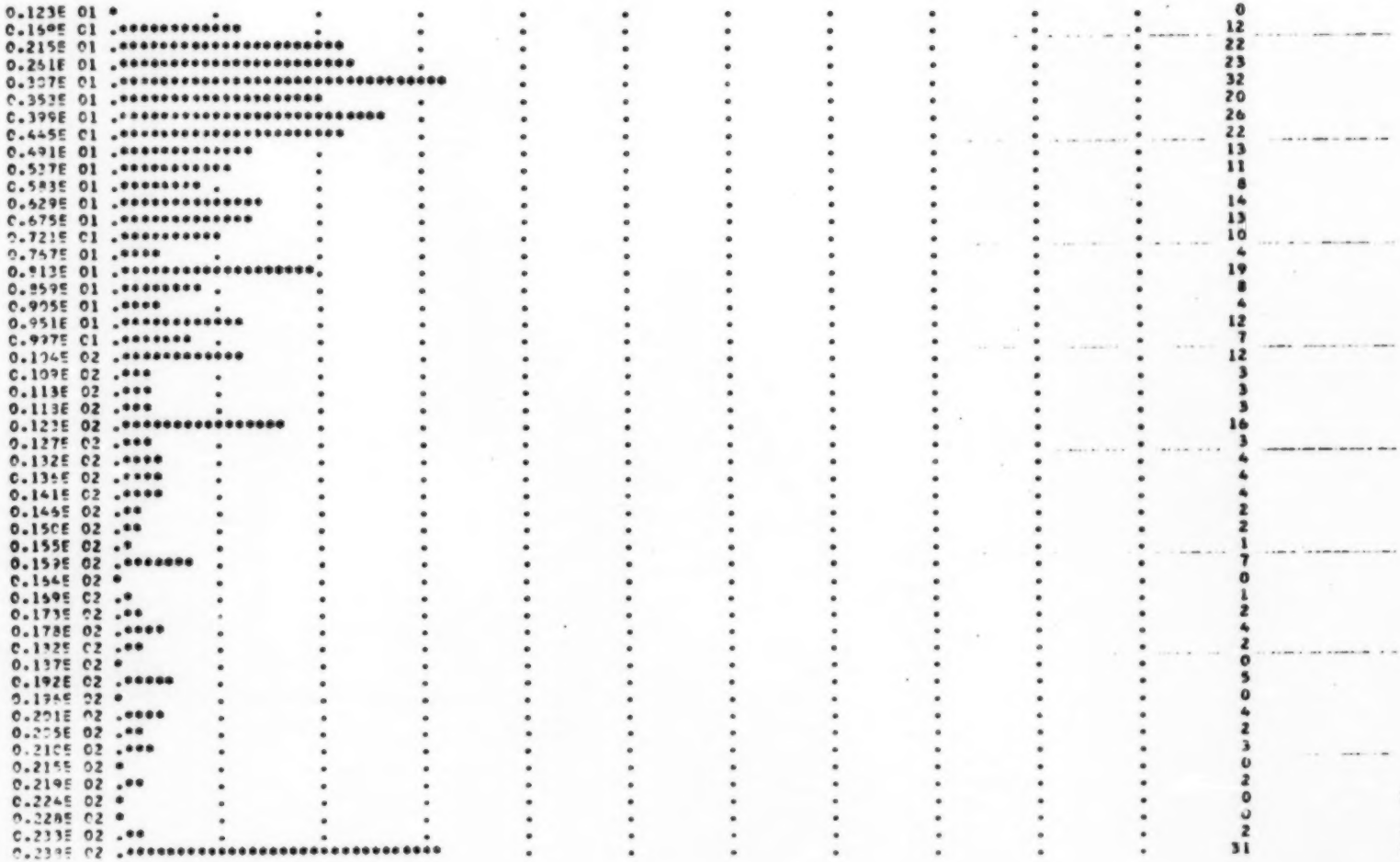

JOINT WINDSPEED RATIO FREQUENCY DISTRIBUTION
1 TO 24HR RATIOS
WINDSPEED CLASS 1

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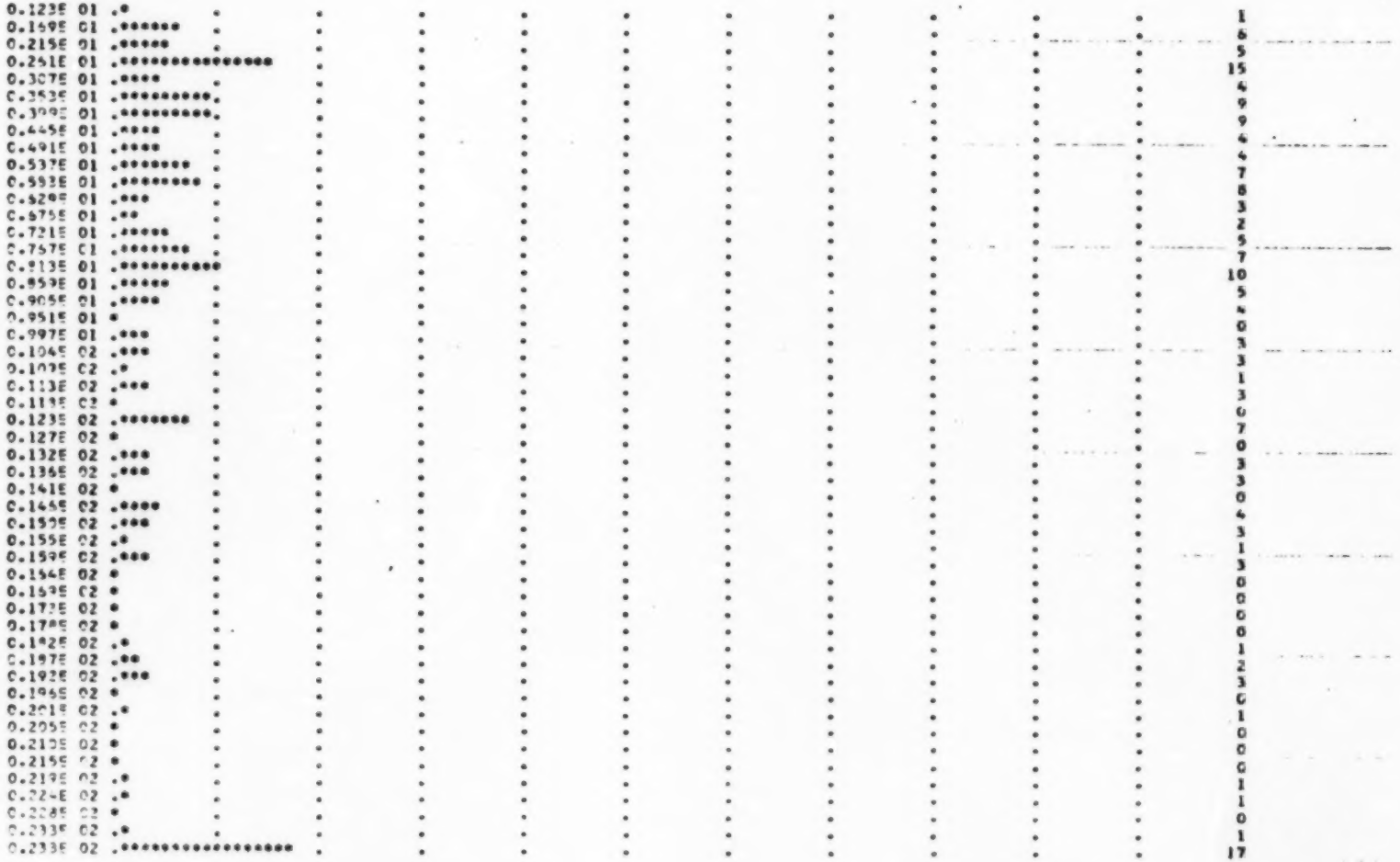

JOINT WINDSPEED RATIO FREQUENCY DISTRIBUTION
1 TO 24HR RATIOS
WINDSPEED CLASS 5

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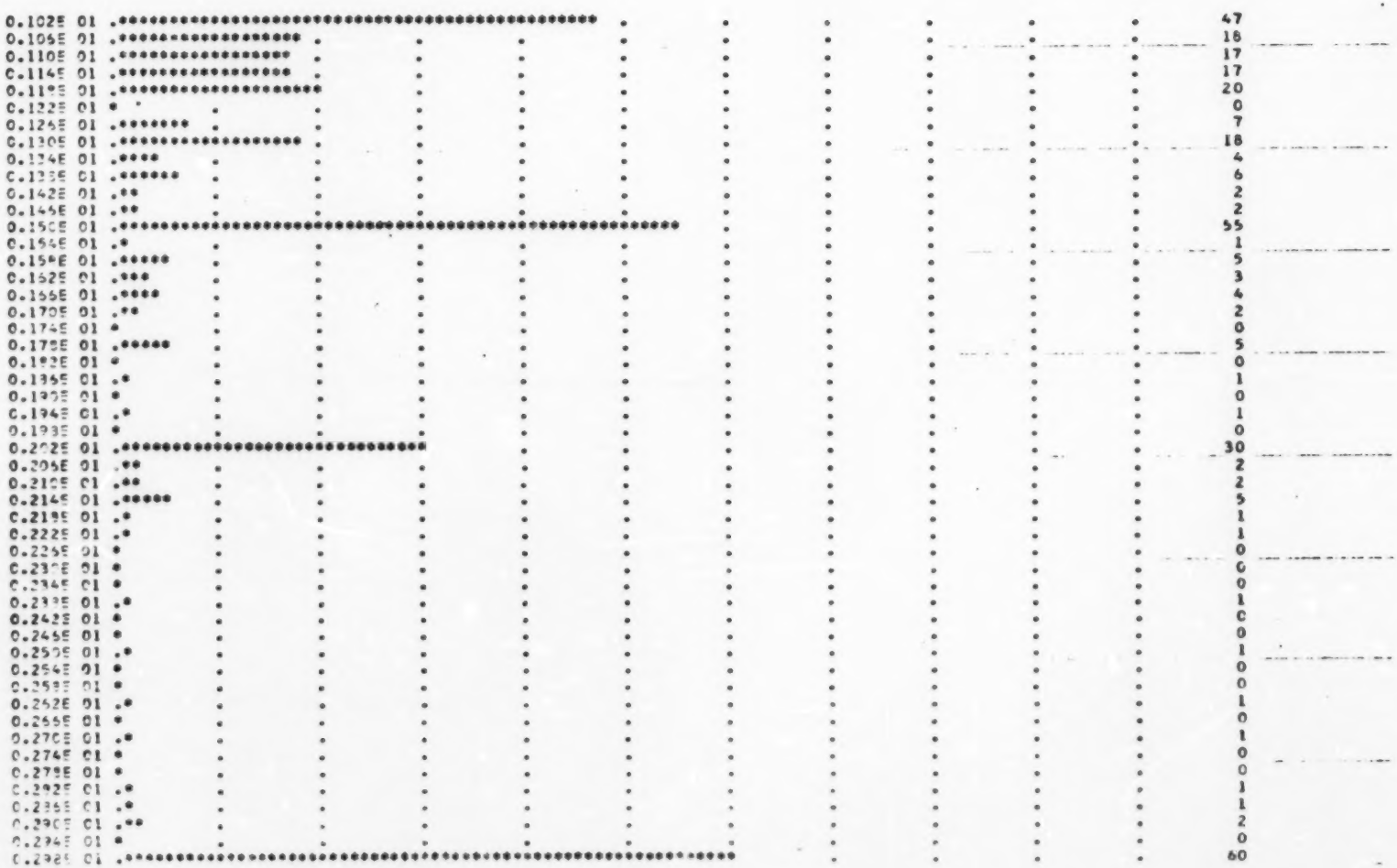

JOINT WINDSPEED RATIO FREQUENCY DISTRIBUTION
1 TO 3HR RATIOS
WINDSPEED CLASS 4

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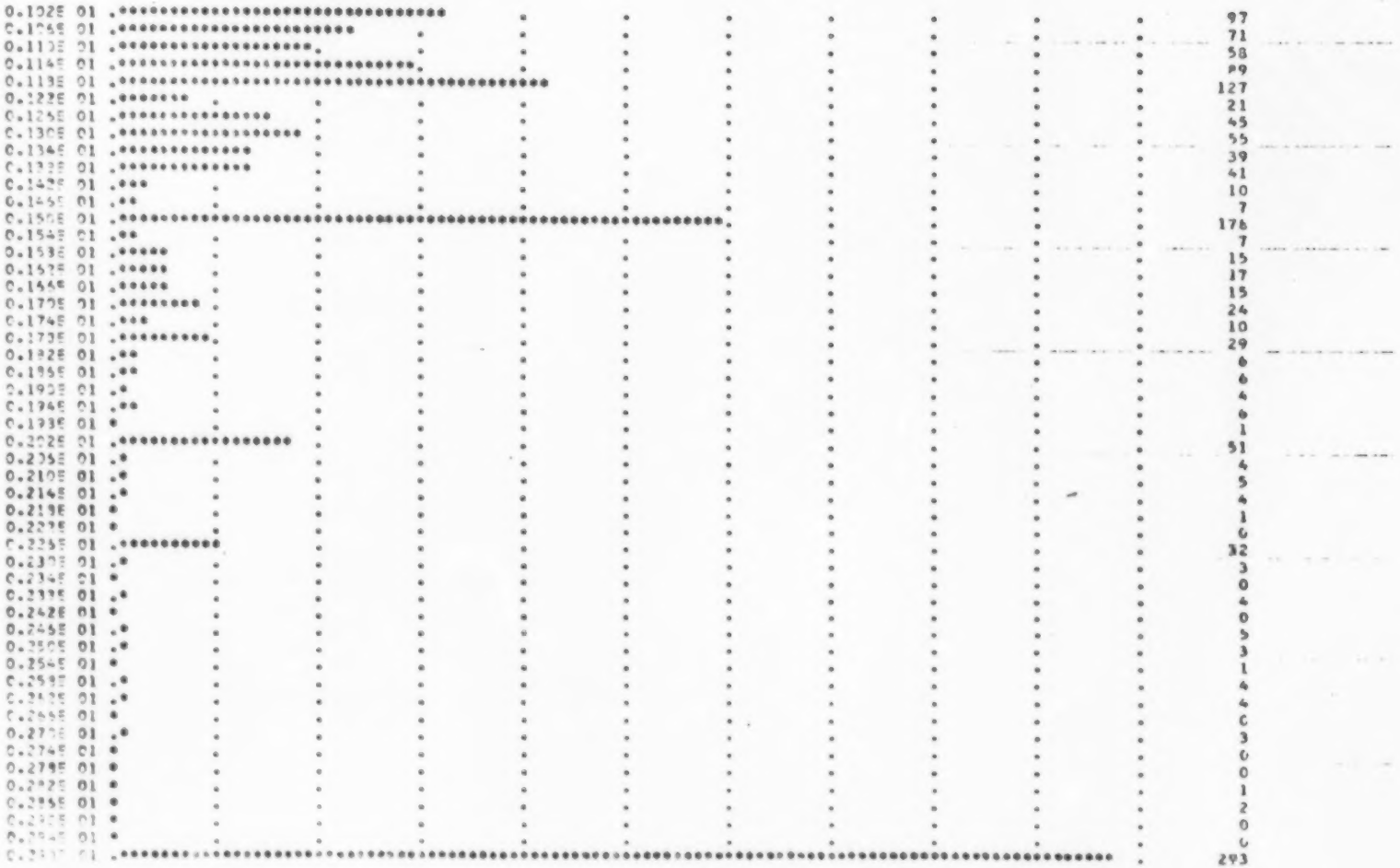

JOINT WINDSPEED RATIO FREQUENCY DISTRIBUTION
1 TO 3HR RATIOS
WINDSPEED CLASS 3

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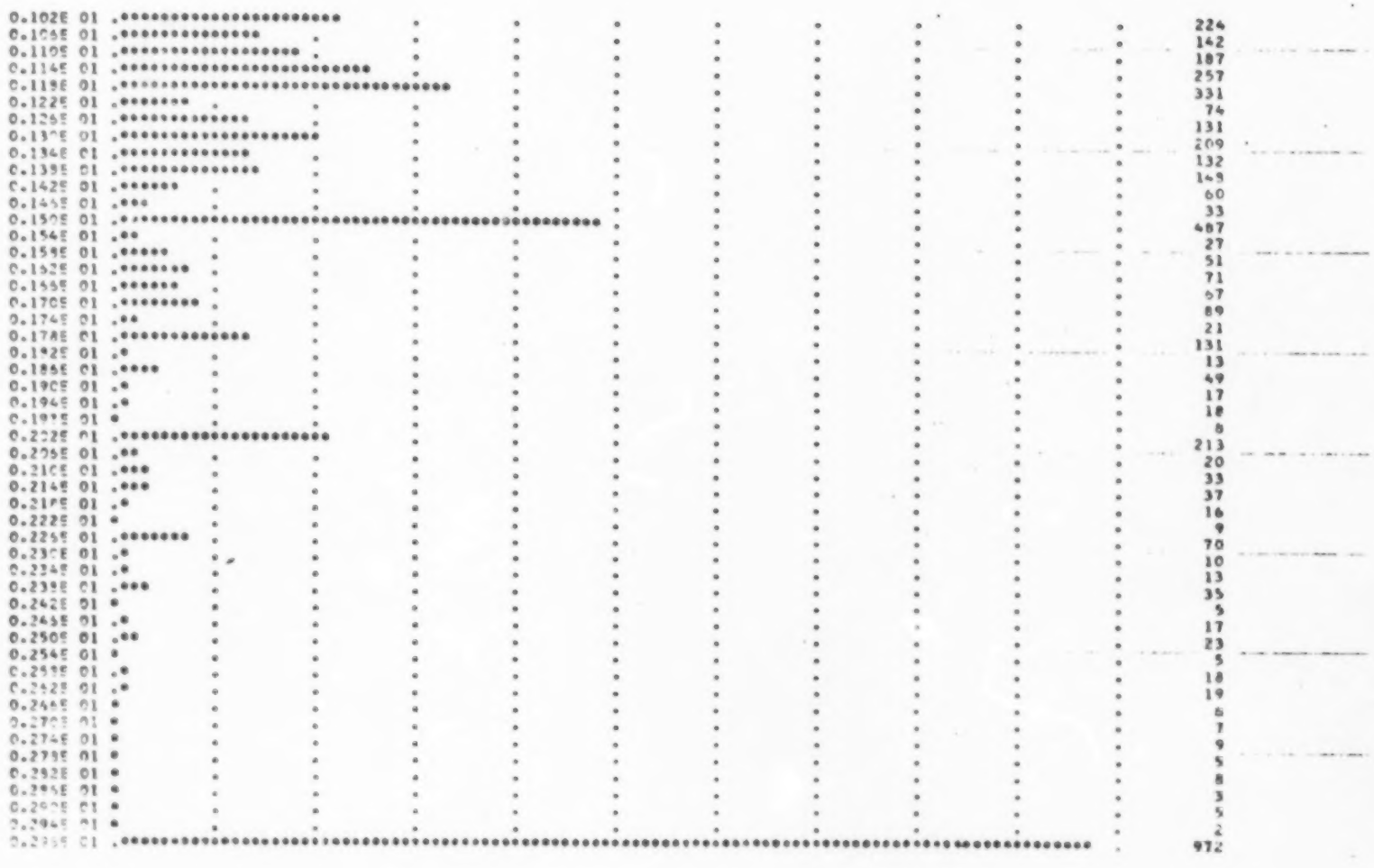

JOINT WINDSPEED RATIO FREQUENCY DISTRIBUTION
1 TO 3HR RATIOS
WINDSPEED CLASS 2

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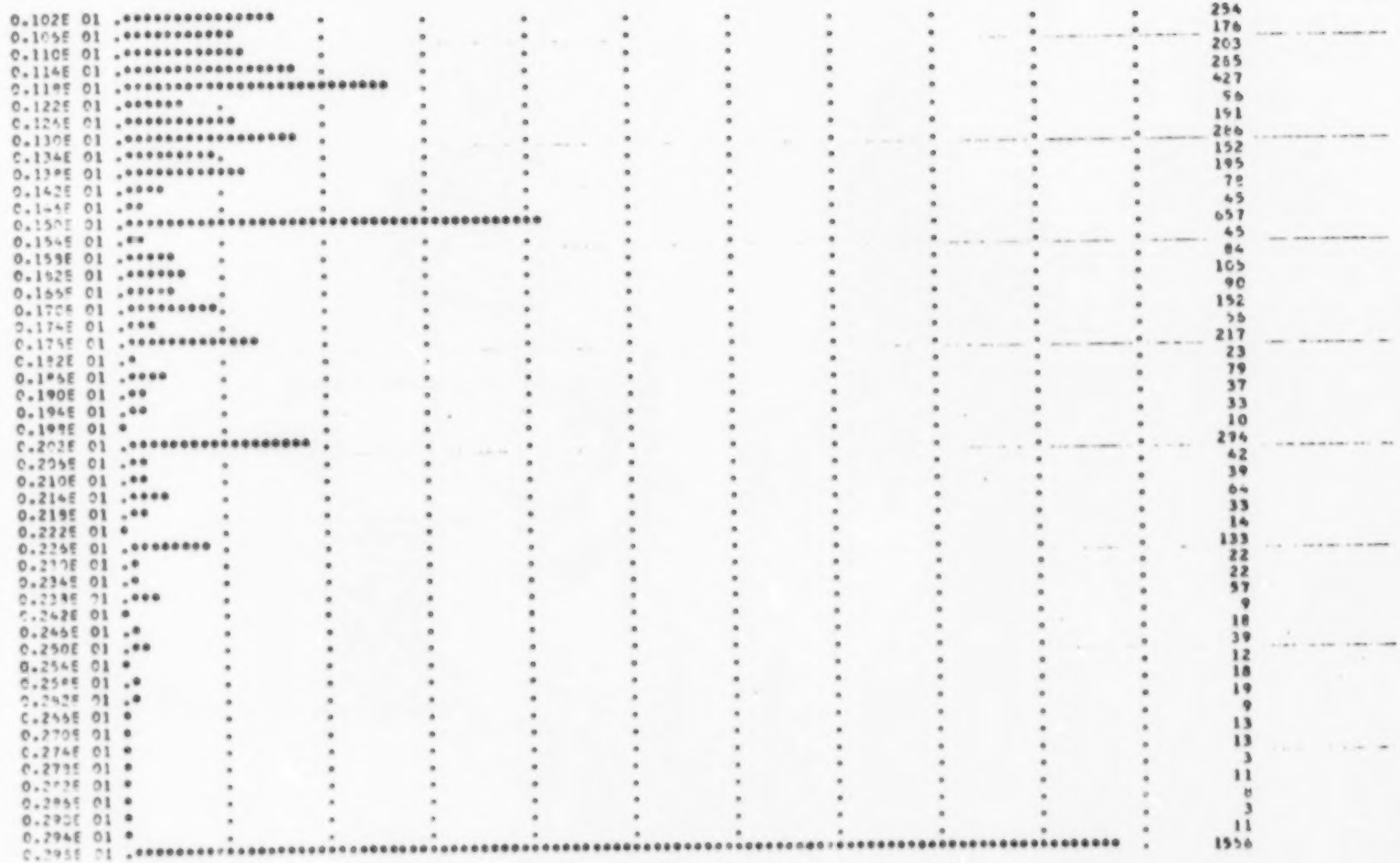

APPENDIX B

DEVELOPMENT OF SOURCE PARAMETERS FROM FPC FORM 67

Source data for the first two model validation runs was taken from FPC Form 67. The average monthly source strengths for SO_2 in 1971 were determined from the plant fuel consumption data given below:

Month	Oil consumption (1000 Bbls)	Avg.% sulfur
January	558	2.02
February	240	1.87
March	429	2.07
April	487	1.89
May	462	2.05
June	185	2 10
July	504	2 09
August	513	2 02
September	466	1.91
October	484	0.90
November	380	0.99
December	432	0.89

Fuel consumption figures were converted from units of 1000 bbls to g/sec as shown in this example for the month of January.

$$\frac{558000 \text{ bbls}}{\text{month}} \times \frac{42 \text{ gallons}}{\text{bbls}} \times \frac{7.88 \text{ lb}}{\text{gallon}} \times \frac{454 \text{g}}{\text{lb}} \times \frac{3.7336 \times 10^{-7} \text{ month}}{\text{sec}}$$

$$= 31303 \frac{\text{g}}{\text{sec}}$$

SO_2 emissions were then found by multiplying the sulfur content percentage by 1.998 (the ratio of SO_2 to S molecular weight) and then applying this percentage to the fuel consumption rate.

$$31303 \frac{\text{g}}{\text{sec}} \times 2.02 \times 1.988 \times 10^{-2} = 1263.4 \frac{\text{g}}{\text{sec}} (SO_2)$$

The following plant operating characteristics were also obtained from FPC 67 data.

Stack height		298 ft	= 90.83 meters
Stack diameter		216 in	= 5.49 meters
Exit gas velocity	at 100% load	= 87.7 $\frac{\text{ft}}{\text{sec}}$	= 26.7 $\frac{\text{m}}{\text{sec}}$
	at 75% load	= 64.5 $\frac{\text{ft}}{\text{sec}}$	= 19.7 $\frac{\text{m}}{\text{sec}}$
	at 50% load	= 40.3 $\frac{\text{ft}}{\text{sec}}$	= 12.3 $\frac{\text{m}}{\text{sec}}$

Since it was indicated on the form that the average boiler capacity factor for the year was 75 percent the second of the three exit velocities was chosen for the model runs.